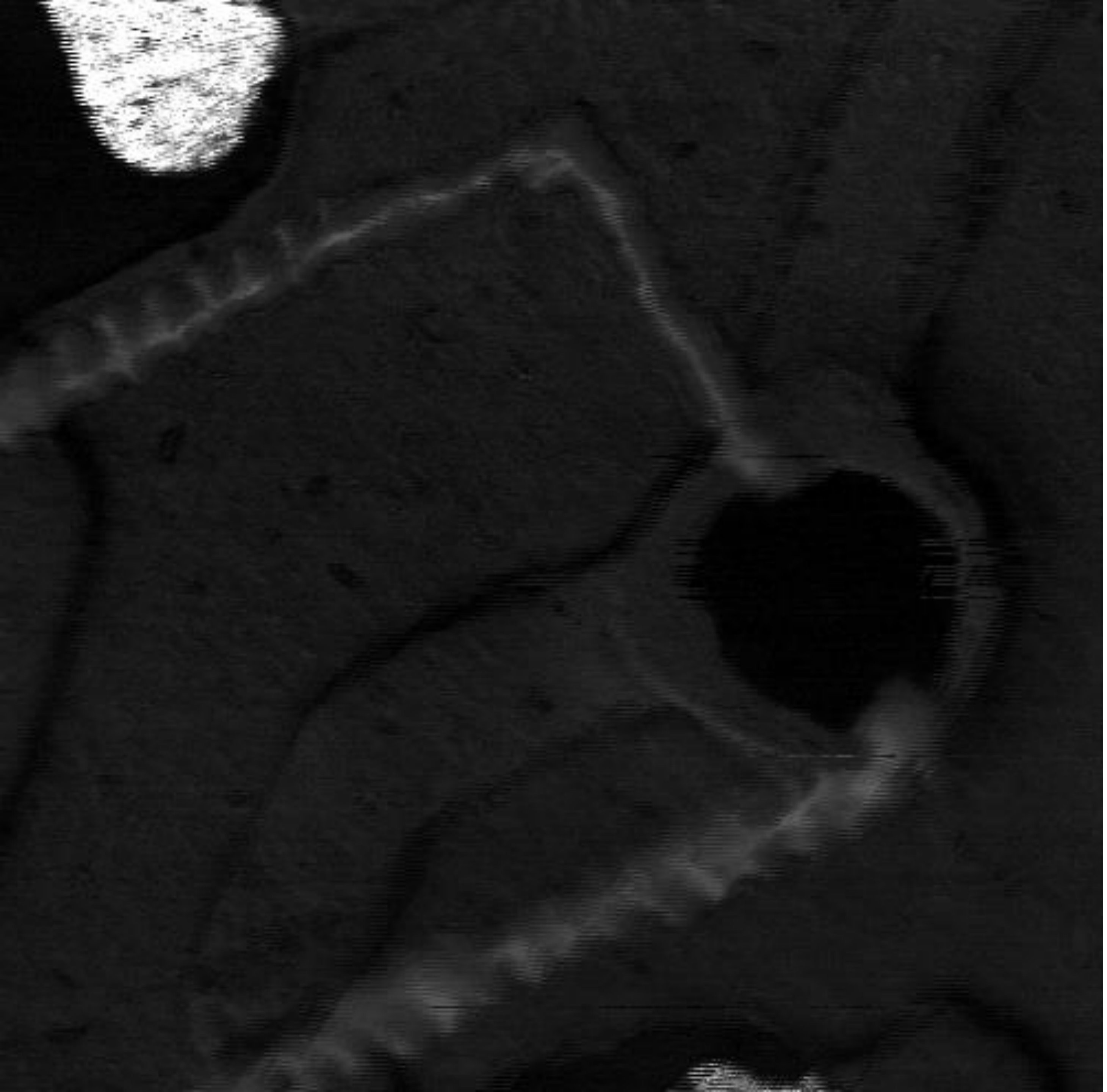


Group 7 Final Presentation

Laser-Scope: The Affordable Confocal Scanning Laser Microscope for Surface Topography

GROUP 7
- JOSEF WOODHOUSE
- LUC THERRIEN
- OMAR CASTRO
- COLLIN BARBER

Meet the team

Josef Woodhouse
Electrical Engineering

Luc Therrien
Photonic Science and Engineering

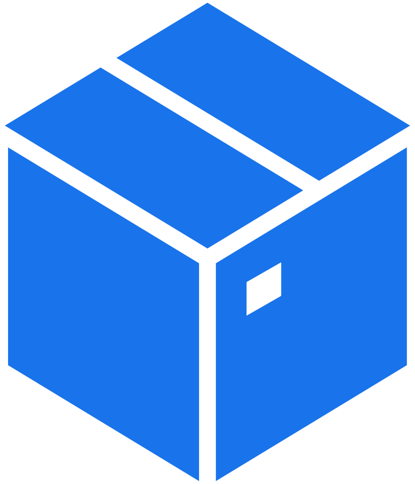
Omar Castro
Computer Engineering

Collin Barber
Photonic Science and Engineering

Motivation and Background

- **Confocal laser scanning microscopy (CLSM)** uses point illumination and a pinhole to block out-of-focus light, enabling cleaner, less invasive imaging.
- Patented 1957 by Marvin Minsky; popularized in the 1970s–80s with the advent of lasers.
- The first commercial CLSM: 1987, Carl Zeiss
- Vital in biological and material sciences
- High-resolution imaging but high cost.
- CLSM in material science: standard for surface texture and roughness characterization

Basic Goals



Basic Goals:

- Maintain total cost under $1000 using off-the-shelf (not obsolete) components from known vendors
- 3D printed housing for all optical components to reduce cost and increase customizability
- Achieve sub-micron movement from the OpenFlexure 3D printed microscope stage
- Detect reflection of the laser on the object-under-illumination (OUI) into the photodiode
- Create 2D greyscale images of surface topography based on the information from the photodiode

Advanced Goals

Advanced Goals:

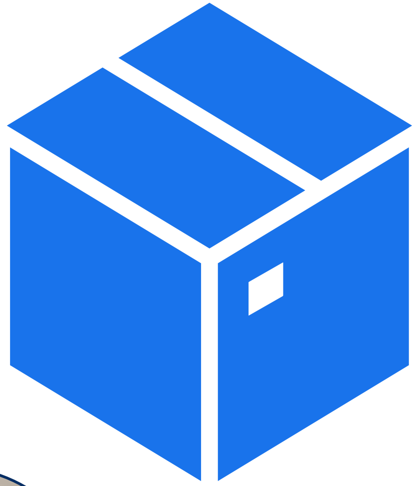
- Make the 3D printed Microscope head adjustable for ease of use and alignment purposes
- Achieve processed images within ~5 minutes after scanning is complete
- Implementation of custom PCBs for laser control, motor control, photodiode power, transimpedance amplifier power, and MCU power.
- Maintain consistent laser spot size of $\sim 1\ \mu m$

Stretch Goals

Stretch Goals:

- Creation of 3D surface reconstructions of samples for higher quality images
- Achieve a resolution of < 1 μm for higher quality images
- Optimize lens systems to account for aberrations
- Let the user interface run in real time with the scanning for data visualization

Objectives

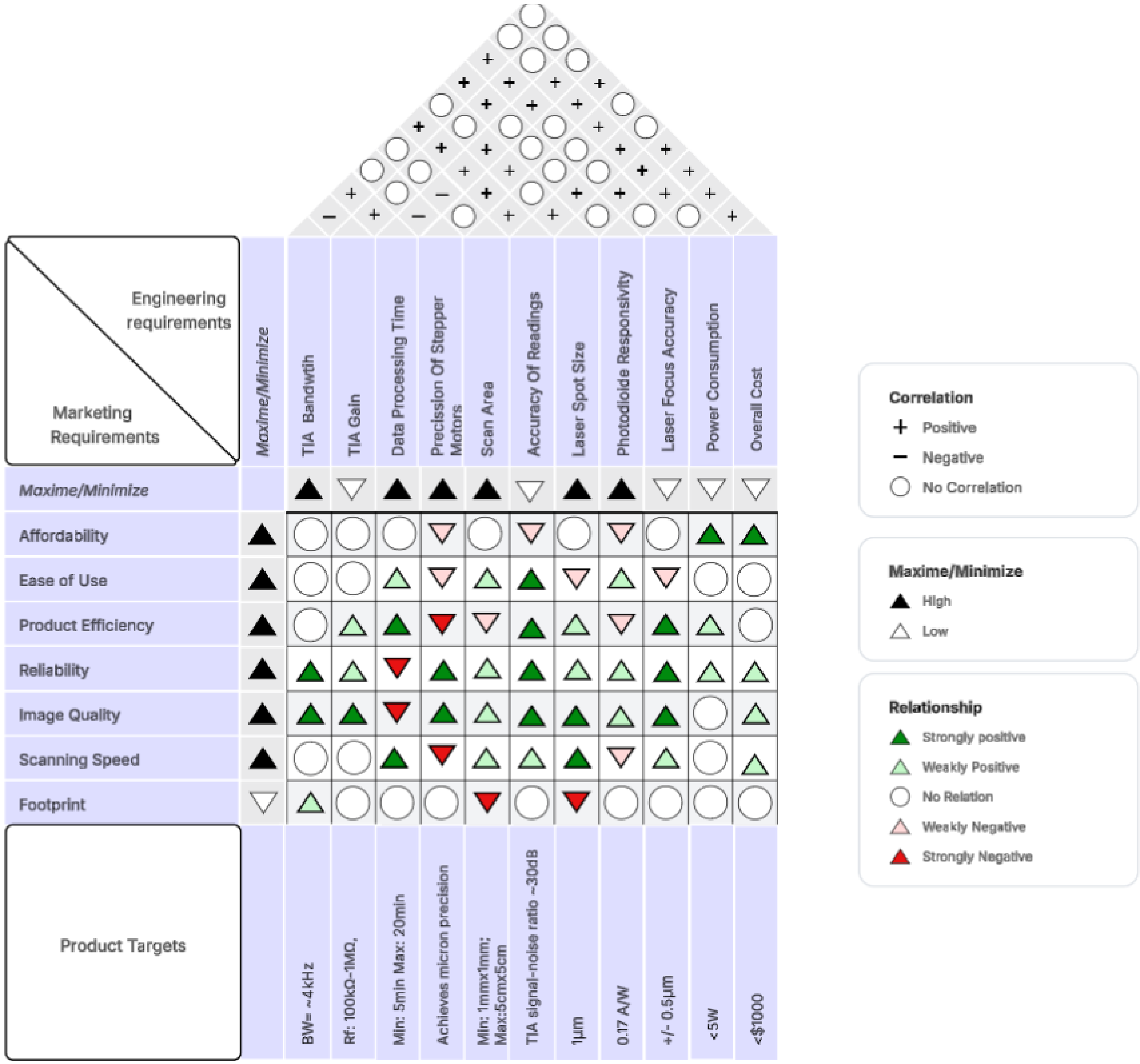


- 405 nm laser with <20 mW of power
- Whole system powered by <20 W
- Achieve > 30dB SNR
- Project footprint to be <1 m x 1 m
- Microscope head/stage to be fully 3D printed and completely open-source
- Must process each pixel of the image in <1 s to reduce photobleaching the image
- All PCB implementations must be compact as well as modular

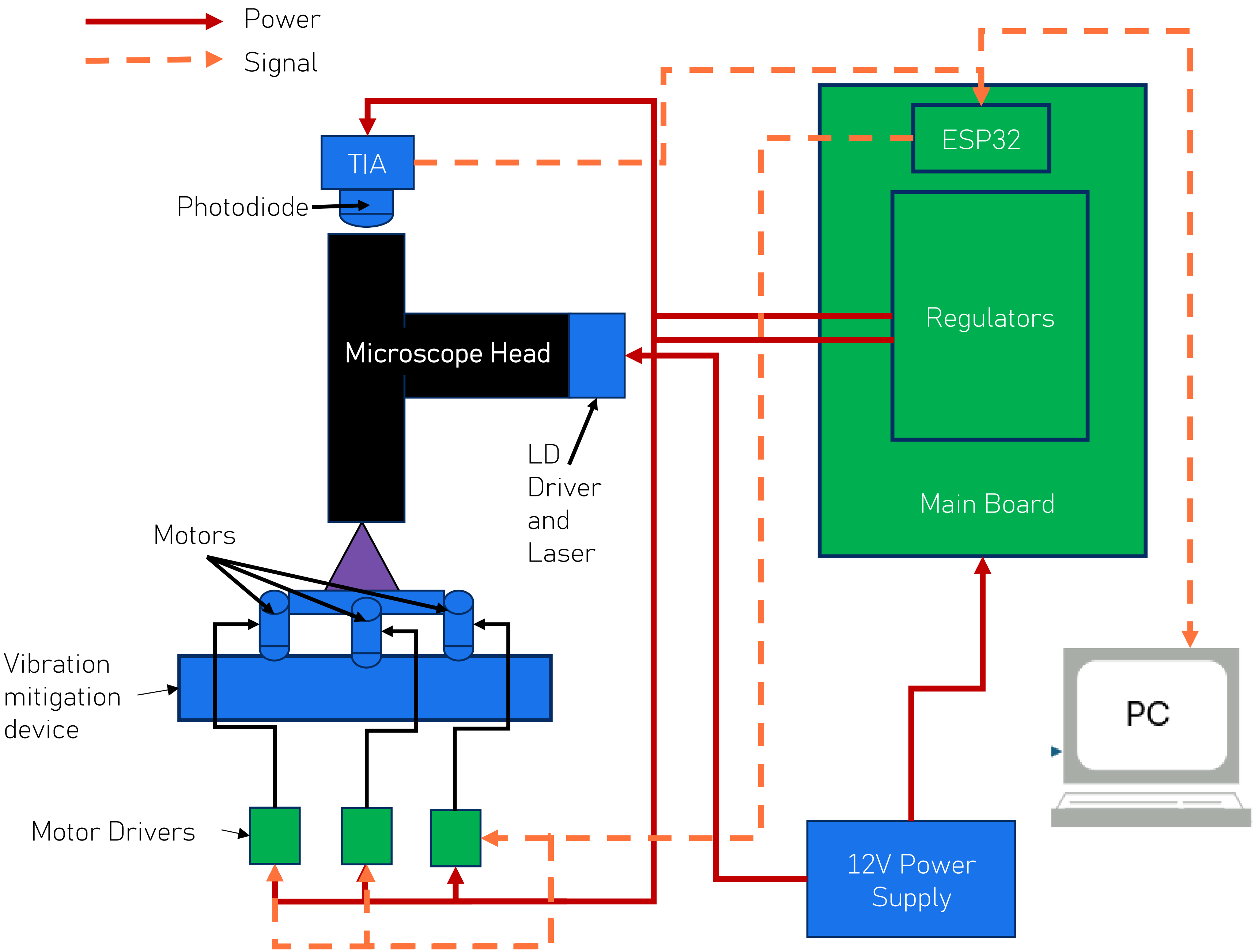
Engineering Specifications

Engineering Requirements	Specification
TIA Bandwidth	1 kHz of bandwidth
TIA Gain	1 x 10^6 V/A
Data Processing Time	5-15 minutes
Stepper Motor Precision	Step Angle = 0.088°
Scanning Area	Min Area = 1mm x 1mm Max Area = 1cm x 1cm
Reading Accuracy	TIA signal-to-noise ratio ~30-40 dB
Laser spot size	10 μm
Photodiode Responsivity	~ 0.6 A/W
Scanning Speed	1mm x 1mm, 64 x 64 pixel scan in ~15 min
Power Consumption	< 20W
Cost	< $1000

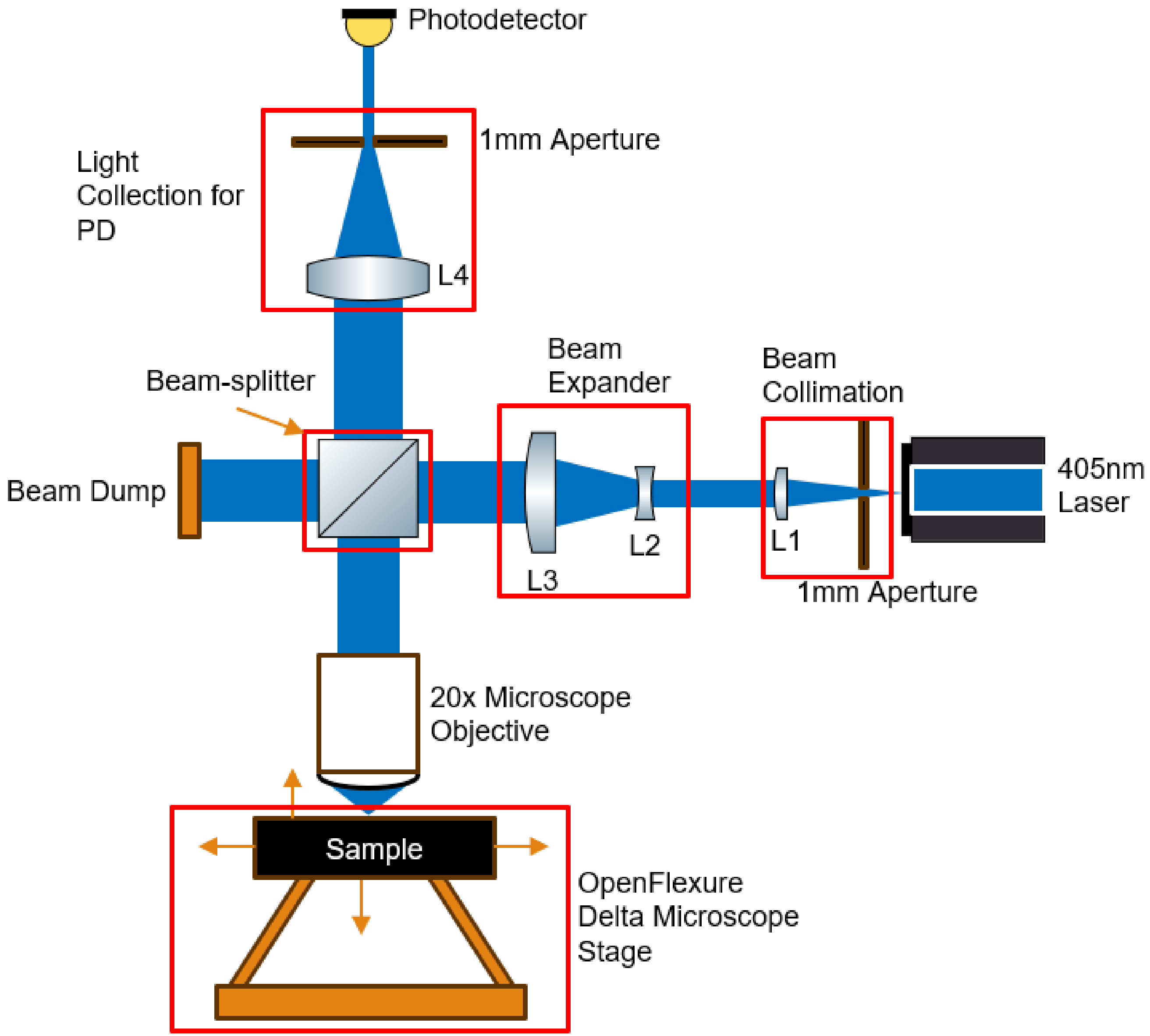
House of Quality



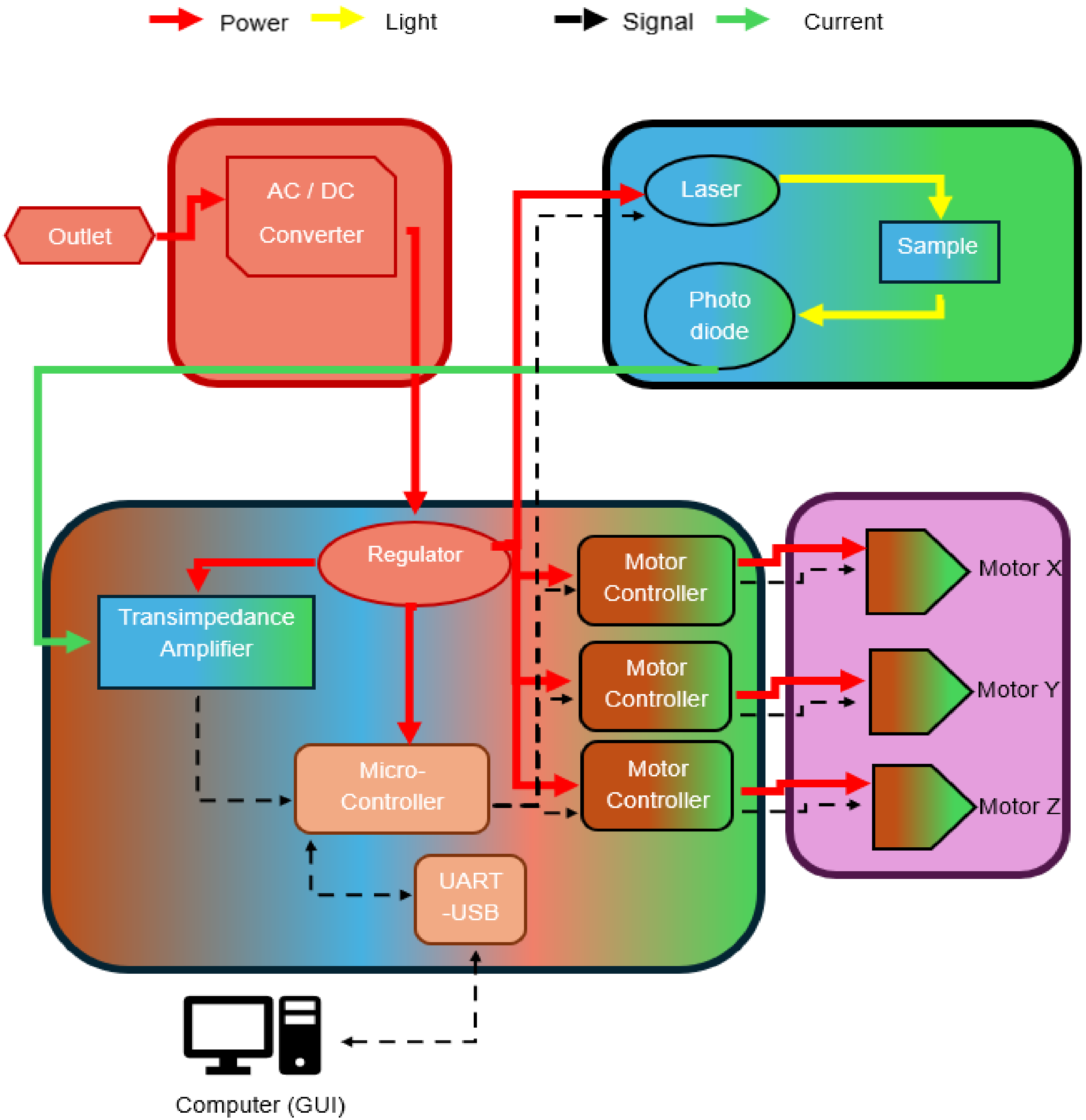
Product Concept



Optical Schematic



Hardware Block Diagram



Hardware Selection – Laser

Technology Selection:

	Diode Lasers	Solid-State Lasers (DPSS)	Gas Lasers	Femtosecond / Pulsed Lasers
Wavelength (nm)	375 – 2000	355, 532, 1064	543, 594, 633, 1060	700 – 2000
Power Consumption	Low (<5 W)	High (10 – 50 W)	Moderate to High (5 – 100 W)	High to Very High (50 – 300 W)
Output Power	1 – 100 mW	100 – 1000 mW	0.5 – 50 mW	~ 100 mW
Beam Quality (M^2)	1.2 - 2.5, Typically elliptical or very divergent	1.1 – 1.3, Gaussian and circular	~ 1.0 Ideal Gaussian	~ 1.0 Ideal Gaussian
Size	Very Compact	Compact (depending on the size of the TEC)	Large	Large
Thermal Regulation Required	No	Yes	No	Yes
Cost	\$10 - \$1000	\$400 - \$15,000	\$500 - \$10,000	\$30,000 - \$150,000
Technology Selection	✓			

Part Selection:

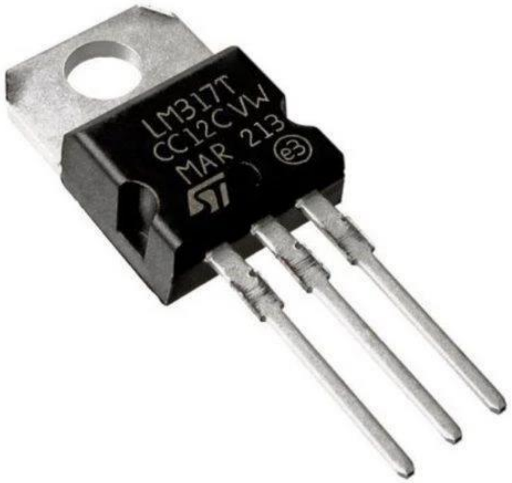
Model	Laser-makers B0788D62ML	Lights88 B072JB71G8	Thorlabs LP405P20
Cost	\$12.89 (for 10 diodes)	\$13.65	\$62.28
Output Power	5 mW	5 mW	20 mW
Size	5.6 mm (TO-18 Package)	Cylindrical (14.5 mm x 45 mm)	5.6 mm (TO-18 Package)
Input Voltage	3 – 5 V	3 – 5 V	4.8 V
Modulation	No	No	Analog/TTL Compatible
Part Selection			✓

The 405 nm laser diode was chosen due to high theoretical resolution and cost.

$$R = \frac{1.22\times\lambda}{2\times NA} = \frac{1.22\times 405\ nm}{2\times 0.40} = 617.6\text{ nm}$$

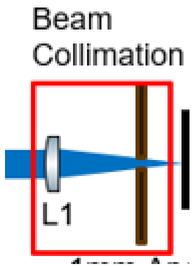
Hardware Selection – Laser Driver

Criteria	Current Control Modules	Passive V-R Conversion	Linear Constant Current Regulator
Cost	Moderate	Low	Low
Output Power	Low-High (Adjustable)	Low	Low
Integration Complexity	Low	Low	Moderate
Input Voltage	0-48V depending on application	Supply Dependent	0-48V depending on application
Technology Selection			✓



Due to its use of integration and low cost the LM317 was selected

Hardware Selection – Collimator (aperture + collimating lens)



Technology Selection:

	2 Aspheric Lenses	Aperture + plano-convex lens
Loss	Very low	Minor
Size	Very Compact	Compact
Cost	>$500	$50
Technology Selection		✓

Part Selection:

	3D Printed Aperture + 35mm f PCX Lens	Changeable Aperture + 35mm f PCX Lens
Aperture Size	1 mm	500 μm – 8mm
Cost	$50	> $100
Part Selection	✓	

This lens was chosen since the focal length of the collimation lens allows for enough room between laser and lens for a 1mm pinhole to allow for spatial filtering.

Hardware Selection – Beam Expander

Technology Selection:

	Keplerian	Galilean
Optical Aberrations	Moderate	Low
Cost	Low	Low
Size (t) (~5x Mag., f1 = 20mm, f2 = 100mm)	~120 mm	~80 mm
Optical Losses	Low (Moderate with aperture)	Low
Technology Selection		✓

Part Selection:

	LF1822-A / LB1869-A	LD2060-A / LA1608-A	LC1054 / LA1986
Total Cost of Lens Pair	$82.30	$87.88	$46.09
Length of Optical System	400 mm	60 mm	100 mm
Magnification	5x	4.99x	5x
Transmission %	~99%	~99%	~92%
Diameters of Lenses	25.4 mm, 25.4 mm	12.7 mm, 25.4 mm	12.7 mm, 25.4 mm
Amount of Optical Aberrations	Low	Low	Moderate
Part Selection		✓	

These optics were chosen to allow for a 5x magnification of the beam size before it enters the microscope objective, while also not taking up too much space

$$\text{M} = \frac{f_2}{f_1} = \frac{75}{15} = 5\text{x magnification}$$

$$L = f_2 + f_1 = 60 \text{ mm}$$

Hardware Selection – Microscope Objective

Technology Selection:

	10x Objective	20x Objective	40x Objective	60x Objective
NA	0.25 - 0.30	0.40 - 0.50	0.65 - 0.75	0.95 – 1.40
Working Distance	~7 – 15 mm	~1 – 5 mm	~0.2 – 0.7 mm	~0.1 – 0.3 mm
Immersion Type	Dry	Dry	Dry, Water	Water, Oil
Field of View	Wide	Moderate - Wide	Moderate - Narrow	Very Narrow
Resolution	Low	Moderate - High	High	Very High
Technology Selection		✓		

Part Selection:

Criteria	AmScope PA20X-INF objective	Olympus PLN 20X objective	Newport LIO-20X objective
Numerical Aperture	0.4	0.4	0.4
Working Distance	1.2 mm	1.2 mm	1.5 mm
Immersion Type	Air	Air	Air
Price	$100	$476	$146
Part Selection	✓		

With the beam being collimated into the objective, the is a need for an infinity plan objective to be chosen. An NA of 0.4 also allows for the depth of field to be slightly bigger than other objectives.

$$DOF_{20} = \frac{2 \times \lambda \times n}{NA^2} = \frac{2(405\ nm)(1)}{0.4^2}$$
$$= 5.06\ \mu m$$

Hardware Selection – Beam Splitter

Technology Selection

Criteria	Plate	Cube	Polarizing
Chromatic Dispersion, other aberration	Low	Moderate	Moderate
Transmittance	High	Moderate	High; selects for chosen polarization
Extinction Ratio	High	High	High
Cost	Moderate	High	High
Technology Selection	✓		

Part Selection

Criteria	Thorlabs BST04	Thorlabs BSW10R	Thorlabs EBS1
Transmission	70:30	50:50	50:50
Wavelength of Operation	400-700nm	400-700nm	400-650nm
Diameter	12.7mm	25mm	25.4mm
Part Selection		✓	

Plate Beam Splitter: chosen for low aberration, high transmittance, and low cost relative to other options

BSW10R: chosen for larger size and transmittance at desired wavelength (405nm)

Hardware Selection – Collecting Lens and Aperture

Part Selection

	Thorlabs LB1761	Thorlabs LB1569	Thorlabs LA1255
Shape	Biconvex	Biconvex	Plano-convex
Focal Length	25.4mm	60mm	50.1mm
Diameter	25.4mm	25.4mm	25mm
Material	NBK7	NBK7	NBK7
Part Selection		✓	

	ID12	ID15	3D Printed Aperture
Diameter	1-12mm	1.2-15mm	2mm
Fixed/Adjustable	Adjustable	Adjustable	Fixed
Price	$62.39	$62.39	Negligible
Part Selection			✓

LB1569: 60mm focal length makes this component the ideal choice; more distance along which to align beam, and easier to position confocal pinhole

$$Spot\ (\mu m) = \frac{4 \times f(\mu m) \times \lambda(\mu m) \times M^2}{\pi \times Beam\ Diam\ .at\ Lens(\mu m)} = \frac{4 \times 0.060^{-6} \times 0.405^{-6} \times 1^2}{\pi \times 0.007^{-6}} = 4.42\ \mu m$$

Hardware Selection – Photosensor

Technology Selection:

	Photodiode	Phototransistor
Sensitivity	Moderate	High
Amplification (by external amplifier)	Necessary	Unnecessary
Response Time	Low (Fast)	High (Slow)
Risk of Saturation/ Photobleaching	Moderate	High
Operating Voltage	Low	Moderate
Technology Selection	✓	

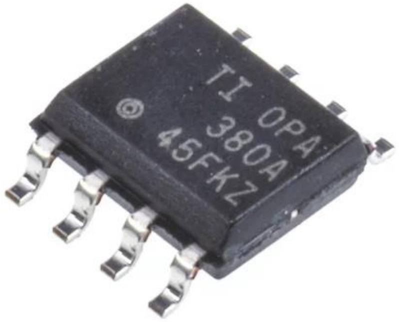
Part Selection:

	FD11A	FDS010	FDS015
Wavelength	320-1100nm	200-1100nm	400-1100nm
Responsivity at Chosen Wavelength	0.17A/W	0.14 A/W	0.19A/W
Active Area	1.21mm^2	0.8mm^2	150µm^2
Dark Current	2pA	0.3nA	0.5nA
Part Selection	✓		

Photodiode preferable to phototransistor due to fast response time, low operating voltage, lower risk of photobleaching

FD11A chosen for largest active area coupled with lowest dark current

Hardware Selection – Transimpedance Amplifier



Criteria	OPA380	OPA381	ADA4530-1	LTC6268
Channels	1	1	1	1
Input Bias Current	50 pA	3 pA	< 20 fA	< 3 fA
Input Offset Voltage	25 μV	25 μV	50 μV	625 μV
Output Swing	Rail-to-Rail	Rail-to-Rail	Rail-to-Rail	Rail-to-Rail
Cost	$4.11	$4.38	$6.00	$5.50
Min Detectable Current	~1nA	~10nA	<1 pA	<1 pA
Gain Bandwidth (GBW)	90 MHz	18 MHz	2 MHz	500 MHz
Use Case	Moderate Speed, low photocurrent	High Precision, low photocurrent	Ultra-low photocurrent signals	High-Speed Ultra-low photocurrent
Part Selection	✓			

Due to its speed, cost and results achieved from testing, the OPA380 was selected

Hardware Selection - MCU

MCU Selection			
	ESP32	Raspberry Pi Pico	Arduino Mega 2560
Core / Clock Speed	Dual Core / 240 MHz	Dual Core / 133 MHz	Single Core / 16 MHz
RAM / Flash Storage	520 KB / 16 MB	264 KB / 2 MB	8 KB / 256 MB
ADC	12-bit / 18 Channels	12-bit / 3 Channels	10-bit / 16 Channels
Digital Pins	34 / 16 PWM Channels	26 / 16 PWM Channels	54 / 15 PWM Channels
Timers / Interrupts	4 / Pin, Timer, External	4 / Pin, Timer	6 / Pin, External
Power Consumption	3.0V - 3.3V 160mA - 260mA	1.8V - 5.5V 90mA - 100mA	7V - 12V 70mA - 90mA
Form Factor	25.5 x 18 mm	51 x 21 mm	101.5 x 53.4 mm
Programming Languages	C, MicroPython	C/C++, MicroPython	Arduino C++
Cost	$4-10	$4-6	$10-45

Due to cost, amount of GPIO Pins, and ADC Resolution the best option was the ESP32.

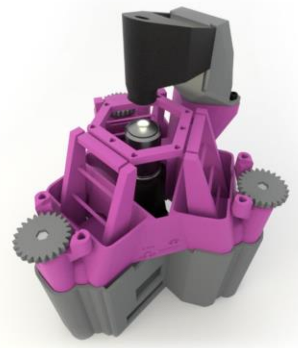
Hardware Selection UART-USB Bridge

Criteria	CP2102	FT232RL	CH30G	PL2303HX
Baud Rate	~1Mbps	>3Mbps	115200-2Mbps	~1Mbps
Pin Package	QFN-28	QFN-32	DIP-16	SSOP-28
Integration Complexity	Low	Medium	Low	Low
Driver Support	Excellent	Excellent	Decent	Some devices unsupported
Available Documentation	Good	Extensive	Basic	Limited
Cost	$5.25	$4.88	$0.48	$0.821
Part Selection	✓			

The CP2102 was selected due to ease of integration, driver support and extensive documentation.

Hardware Selection – Microscope Stage

OpenFlexure Delta Stage



	Manual Stage	Motorized Linear Stage	Piezoelectric Z-Stage
Moveable Axes	X, Y	X, Y, Z	Z only
Resolution	> 10 μm	5 – 0.01 μm	< 10 nm
Travel Range	10 – 50 mm	10 – 100 mm (X, Y), 5 – 25 mm (Z)	100 – 400 μm
Repeatability	Low	Moderate - High	High
Speed	Slow (manual movements)	1 – 20 mm/s (depending on motor controller)	< 1 mm/s
Power Consumption	N/A	10 – 50 W	< 5 W
Cost	Very Low	Low – Moderate	High
Technology Selection		✓	

This microscope stage was chosen due to cost, ease of usability, as well as high lateral resolution for very small movements

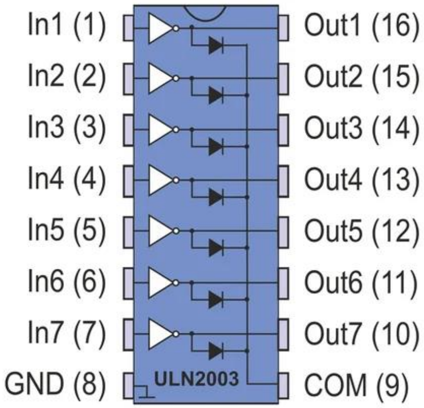
Hardware Selection – Stepper Motors

Criteria	28BYJ-48	NEMA 8 20BYGH	15BY25
Step Angle	0.088°	1.8°	18°
Torque	~34 mN·m	~12 mN·m	~3-5 mN·m
Microstepping Resolution	Up to 4096 Steps/revolution	200 Steps/Revolution	20 Steps/Revolution
Voltage/Current Draw	5V/~240mA	~5-6V/~300mA	3-5V/ <100mA
Cost	$1-2	$10-$15	$4-$6
Part Selection	✓		

The 28BYJ-8 Motors were selected due to their low cost and compatibility with the OpenFlexure Delta Stage

Hardware Selection – Stage Motor Controllers

Criteria	ULN2003	A4988	DRV8825
Driver Type	Darlington Transistor Array (Unipolar)	Chopper Stepper Driver (Bipolar)	Chopper Stepper Driver (Bipolar)
Cost	$1-2 (May come with selected motors)	$2-4	$3-6
Input Type	4-step sequence	Step/Direction	Step/Direction
Max Current per Phase	500mA	1A	1.5A
Voltage Range	5-12V	8-35V	8.2-45V
Protection	Basic Flyback Protection	Thermal Shutdown, Overcurrent & Undervoltage	Thermal Shutdown, Overcurrent, Undervoltage, Crossover
Part Selection	✓		



The ULN2003 Driver was selected due to their ease of use, and inclusion as a dev board for ease of testing.

Power Distribution

Part	Supply Voltage (V)	Current Drawn (A)	Power Consumed (W)
Laser Diode (LP405P20)	5.14V	~31 mA	0.15W
Laser Driver (LM317)	12V	31mA	0.15W
Charge Pump (LT1054)	5V	~30-40mA	0.2W
Photodiode (FD11A)	-5V	N/A	N/A
TIA (OPA380)	3.3V & 5V	0.76 mA	38mW
3x Motors (28BYJ-48)	5V	720 mA (240 mA each at stall)	8.64W
3x Motor Controllers (ULN2003)	5V	~4.2 to 6 mA (total)	0.7W
MCU (ESP32)	3.3V	~20–60 mA (300mA peak)	0.2W
UART-USB (CP2102)	5V	~30-40mA	0.2W
Buck Converter (LM2596)	12V	0.4–0.6A	7.2W
LDO Regulator (LM1085-3.3)	5V	~85mA	0.42W
Total Power			~18.9W

Power Supply – AC/DC Converter

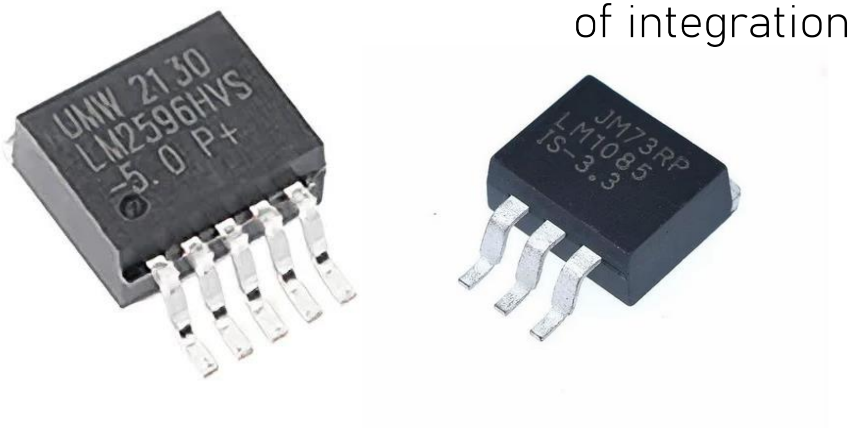
Criteria	Mean Well LRS-50-12	RECOM RAC60-12K/OF	Mean Well LRS-75-12
Output Voltage	12 V	12 V	12 V
Max. Current Output	4.2 A	5A	6.2A
Power Rating	50W	60W	75W
Efficiency	~88%	~89%	~89%
Protections	Short Circuit, Overload, Overvoltage	Short Circuit, Over-temperature, Overvoltage	Short Circuit, Overload, Overvoltage
Cost	$11-13	$25-30	$15-18
Part Selection	✓		

The Mean Well LRS-50-12 was selected due to low cost and appropriate ranges for all values.

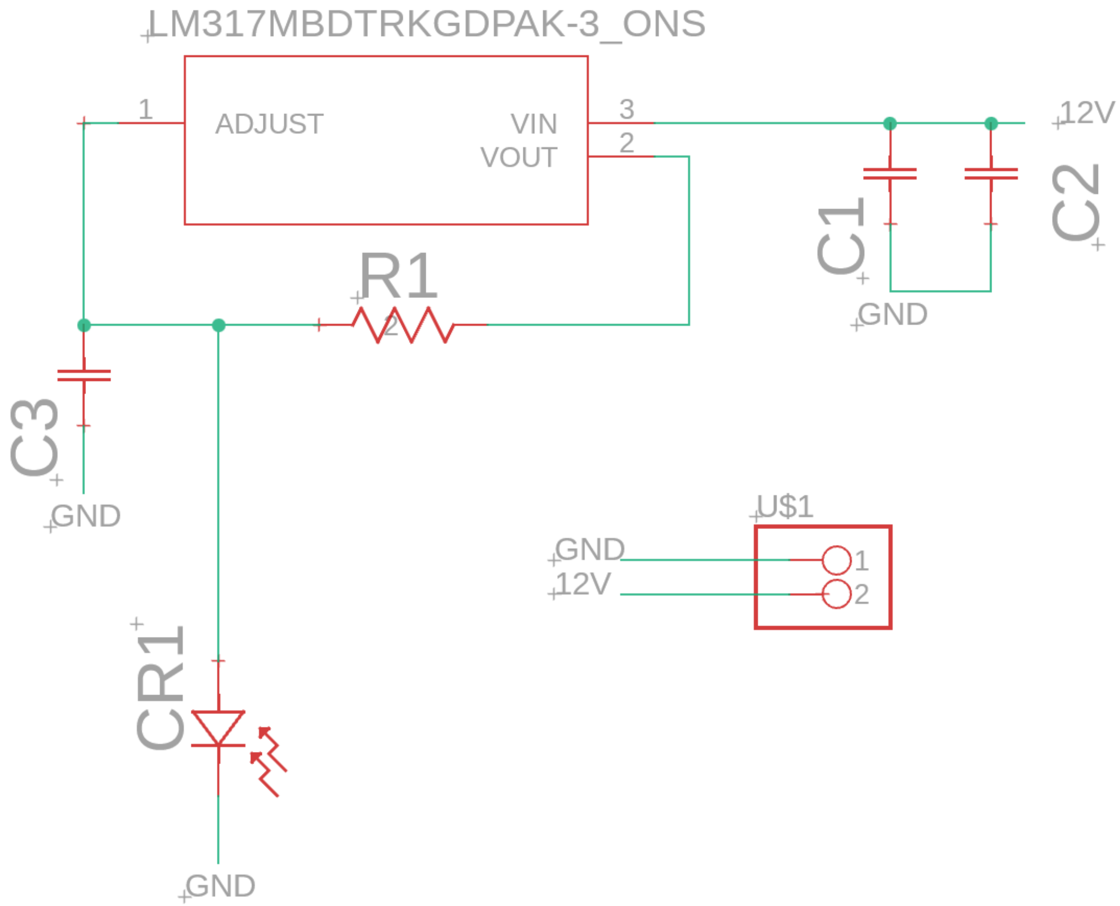
Hardware Selection – 5V & 3.3V Regulators

Criteria	LM1085IT-3.3	L7805CV	LM2596	MP1584EN
Type	Linear (LDO)	Linear	Buck	Buck
Output Voltage	3.3V	5V	3.3-12V (adjustable)	0.9-5.5V
Output Current	3A	1.5A	3A	Up to 3A
Dropout/Switching Frequency	~1.3 Dropout	~2V dropout	150kHz	800kHz
Efficiency	~60-70%	~55-65%	Up to 92%	~90%
Cost	$1.84	$0.49	$2.83	$2.84
Technology Selection	✓		✓	

The LM2596-5.0 & LM1085IT-3.3 were selected due to low cost and ease of integration



PCB Design – Laser Driver

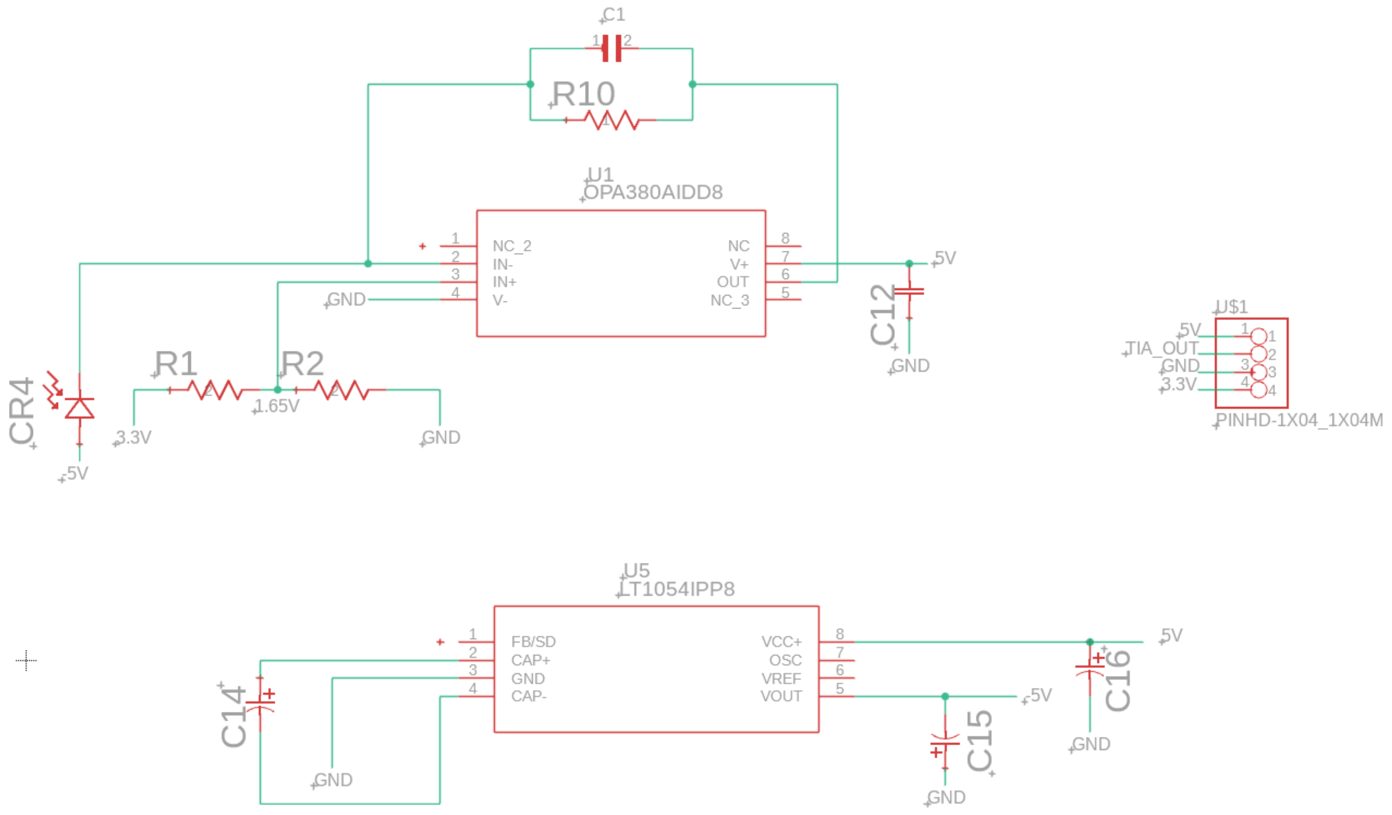


PCB Design – Laser Driver

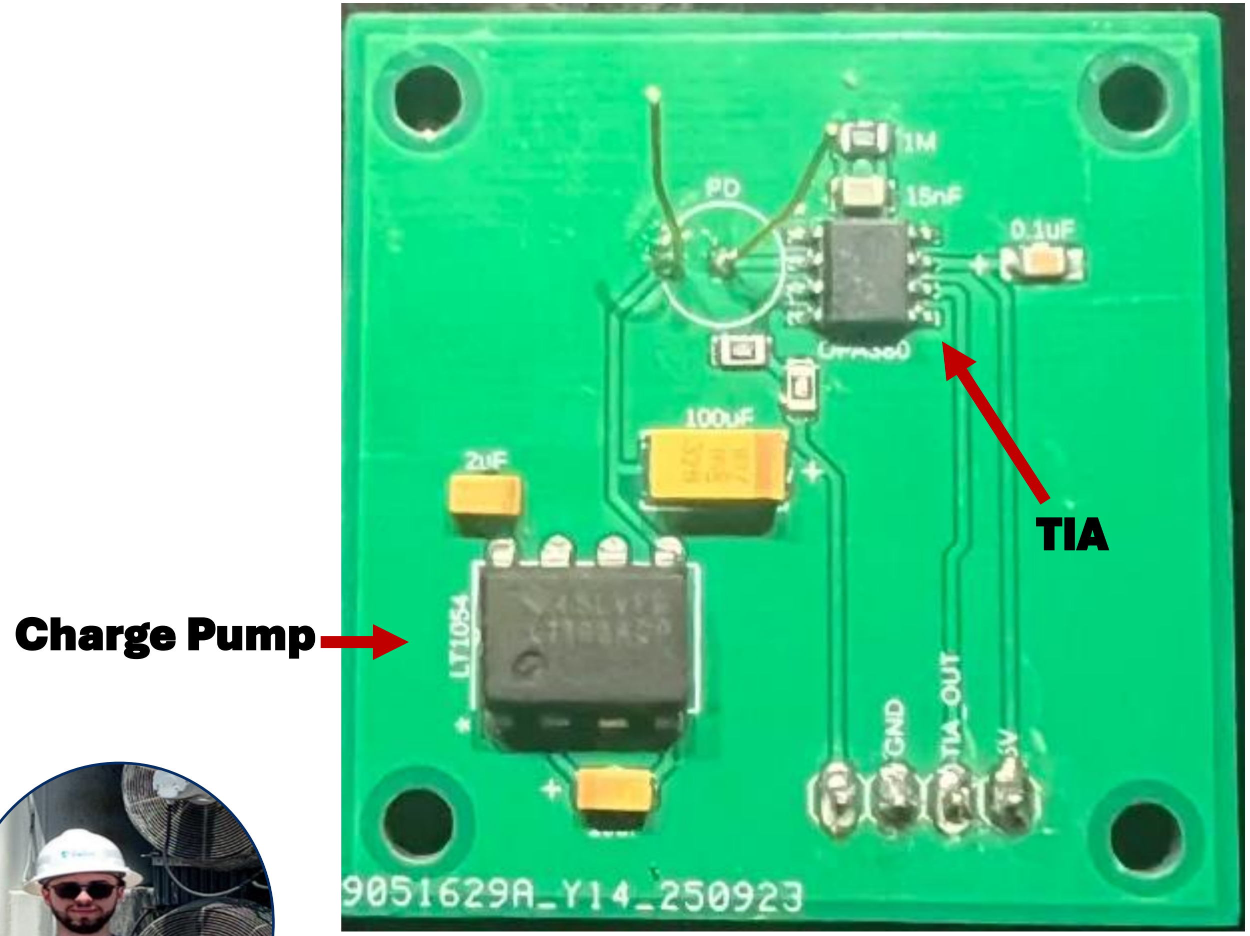
Laser Diode

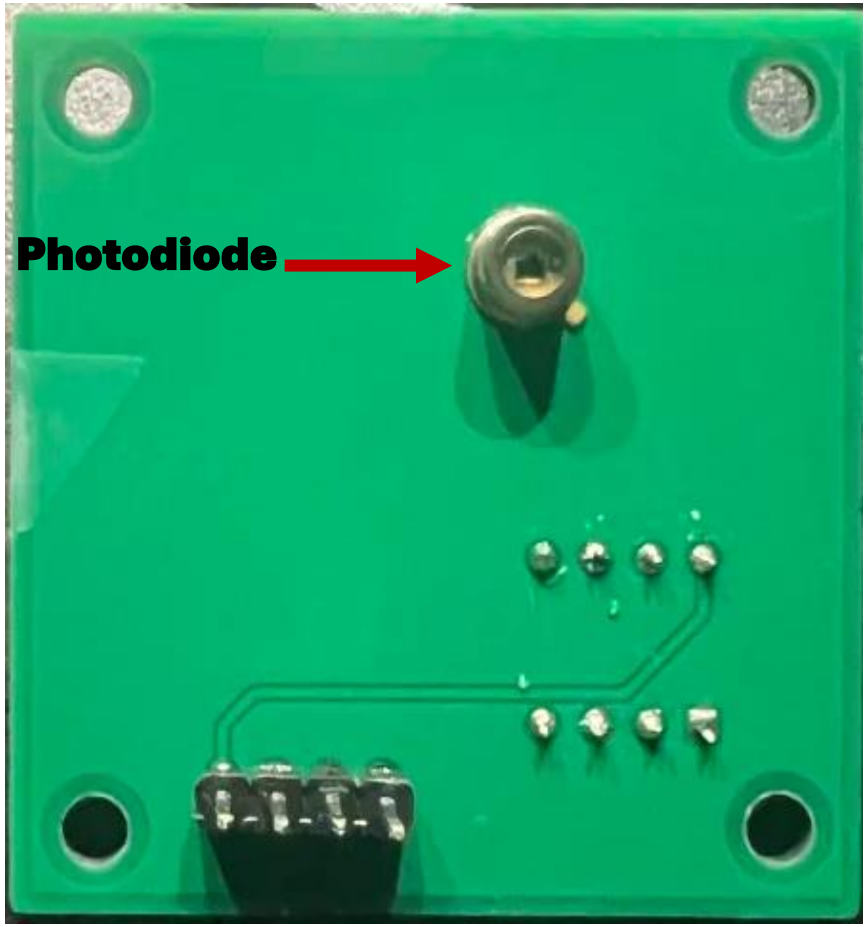
LM317 in constant current mode

PCB Design – Transimpedance Amplifier

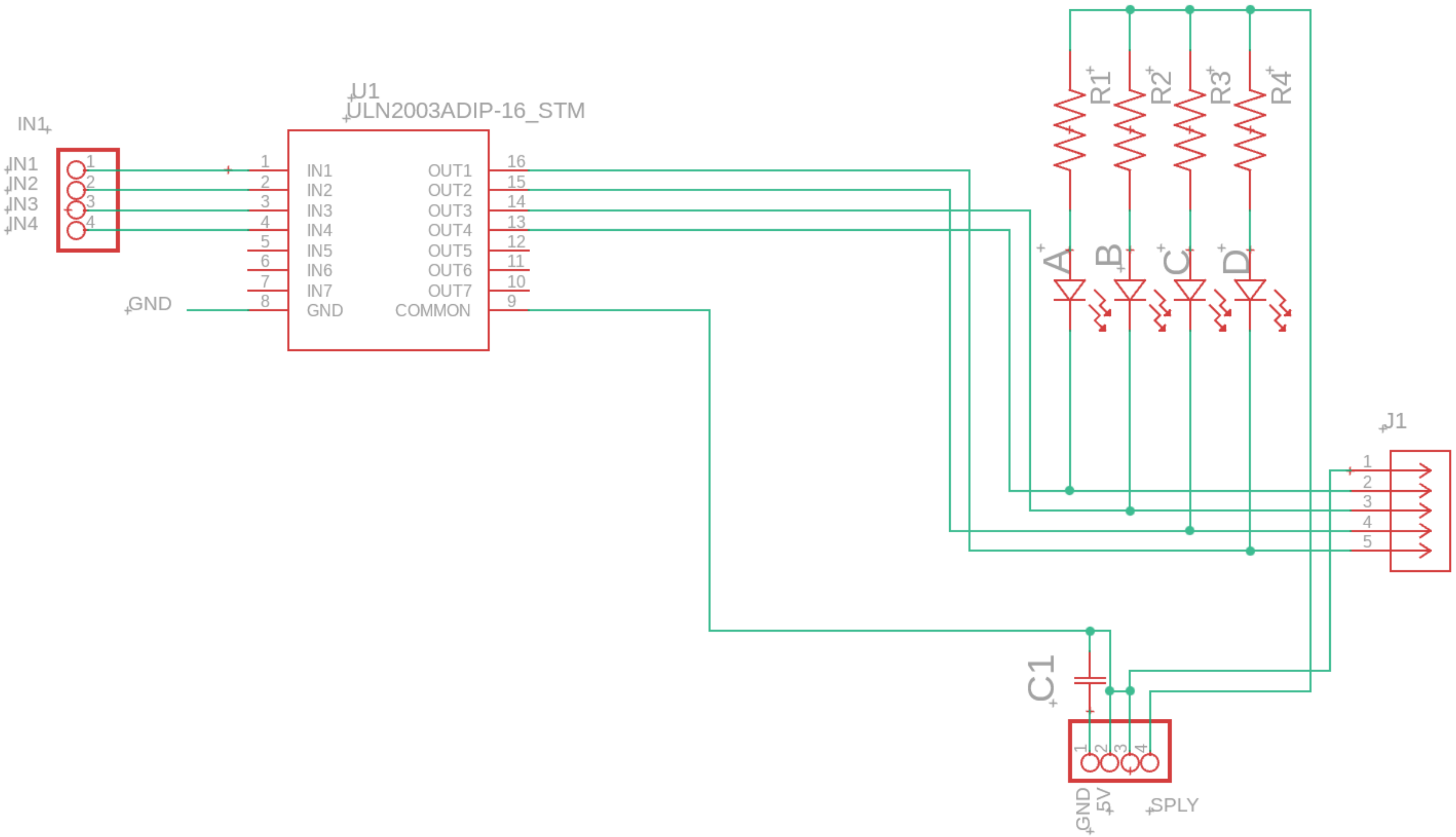


PCB Design – Transimpedance Amplifier





PCB Design – Motor Controllers

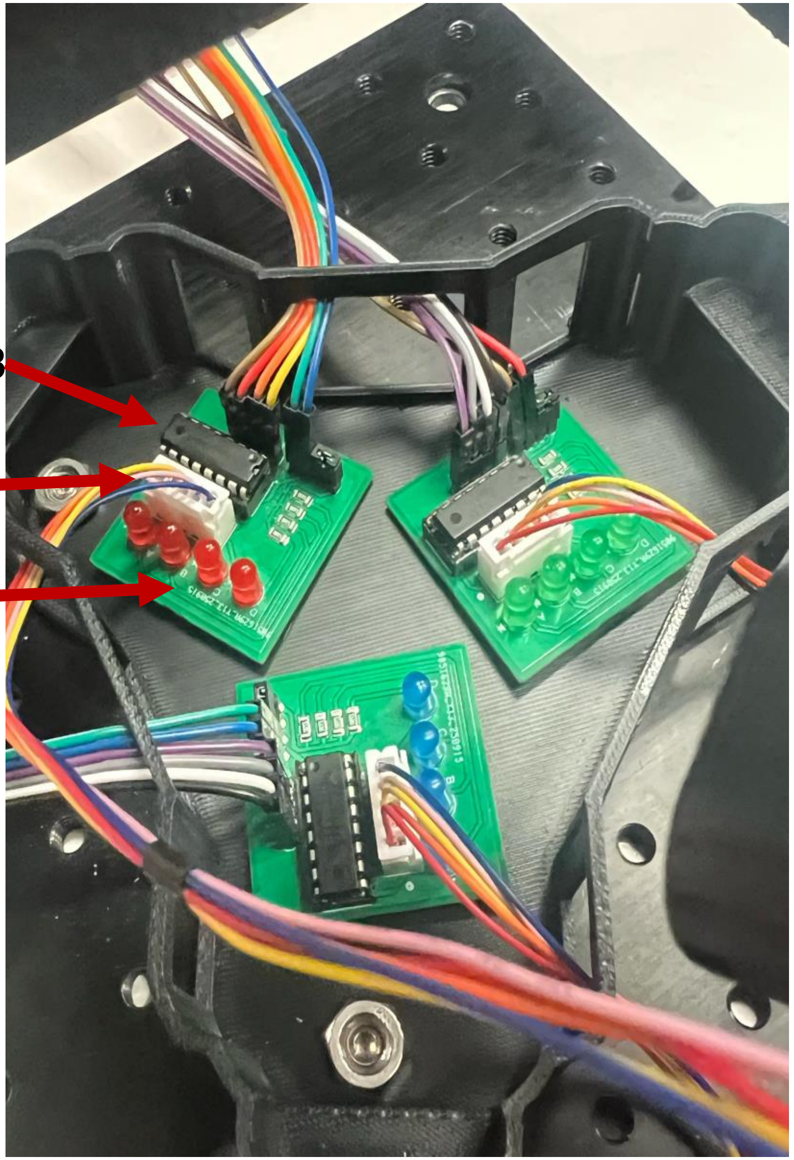


PCB Design – Motor Controllers

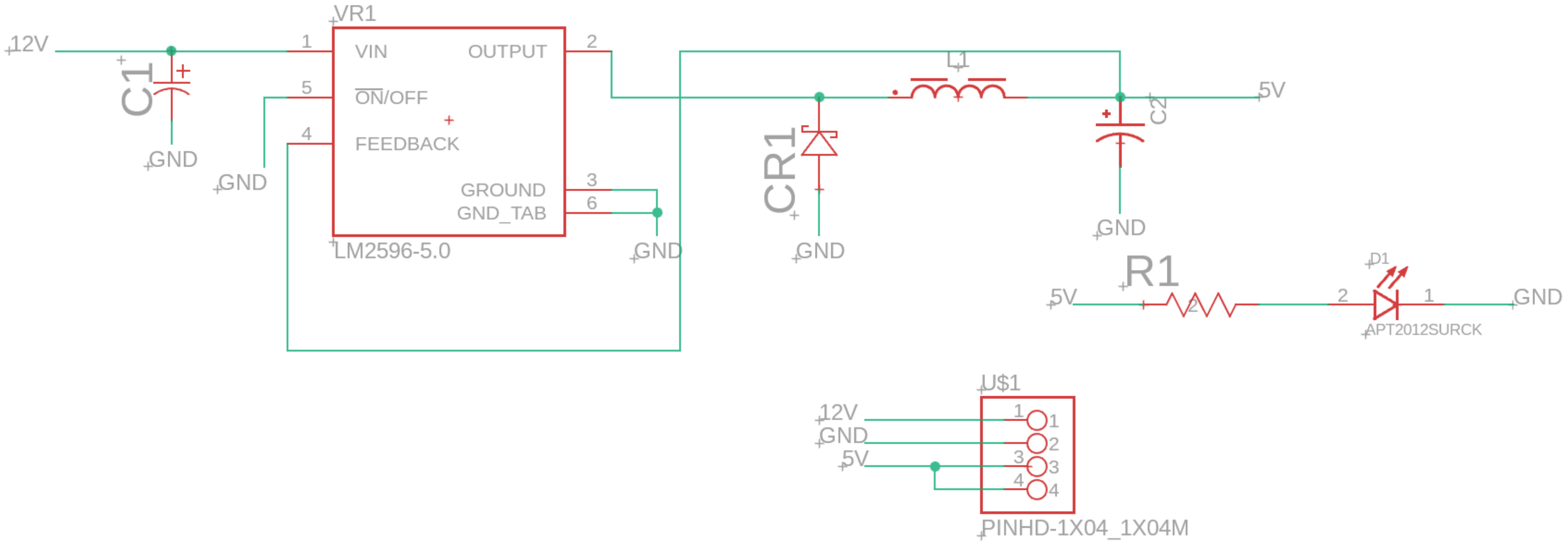
ULN2003

Motor Connector

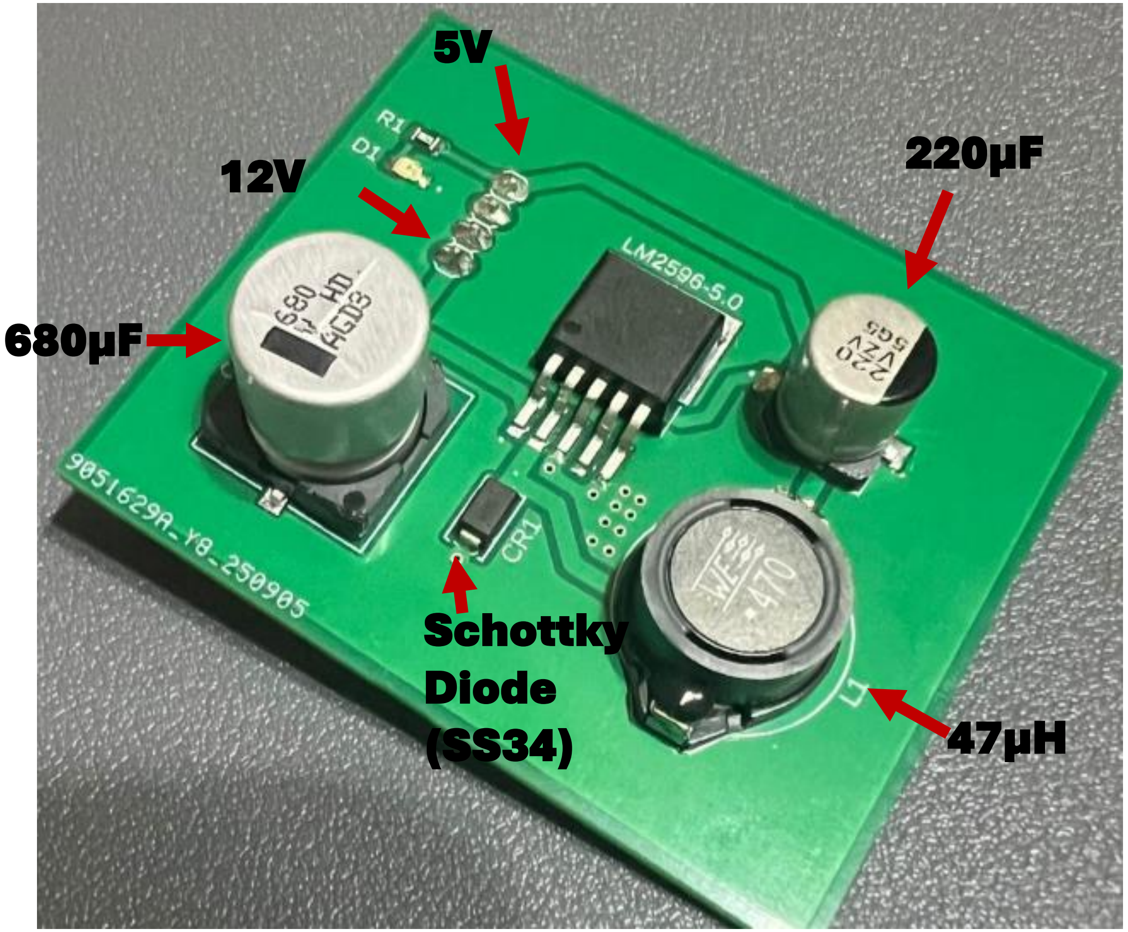
Phase indicators



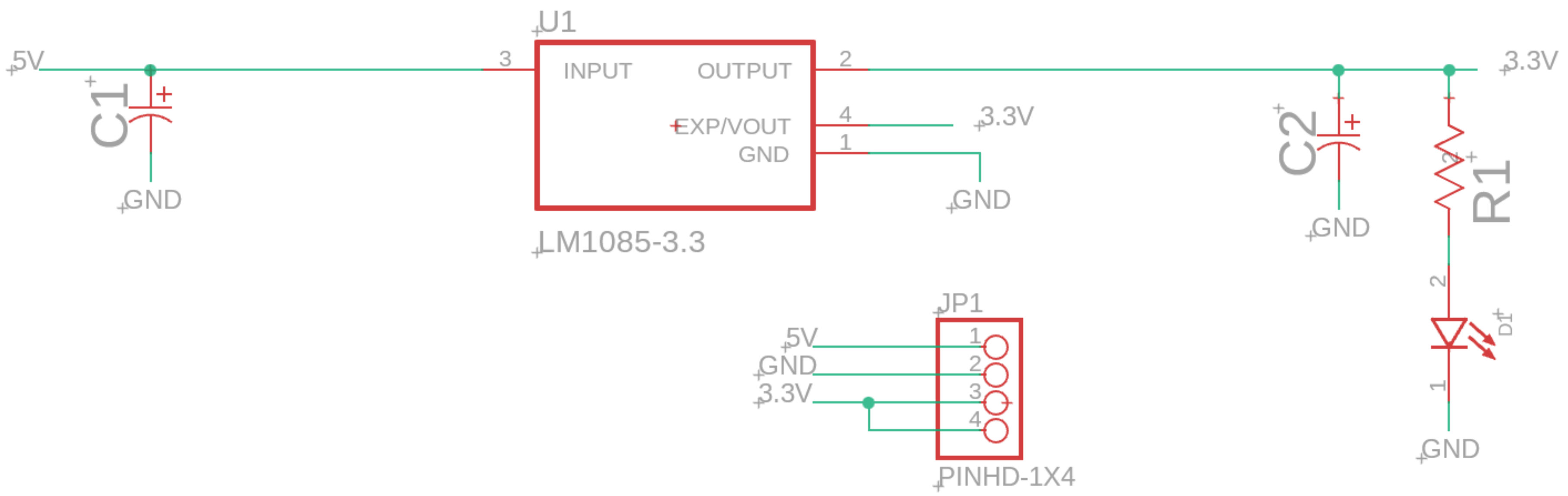
PCB Design – 5V Regulator



PCB Design – 5V Regulators

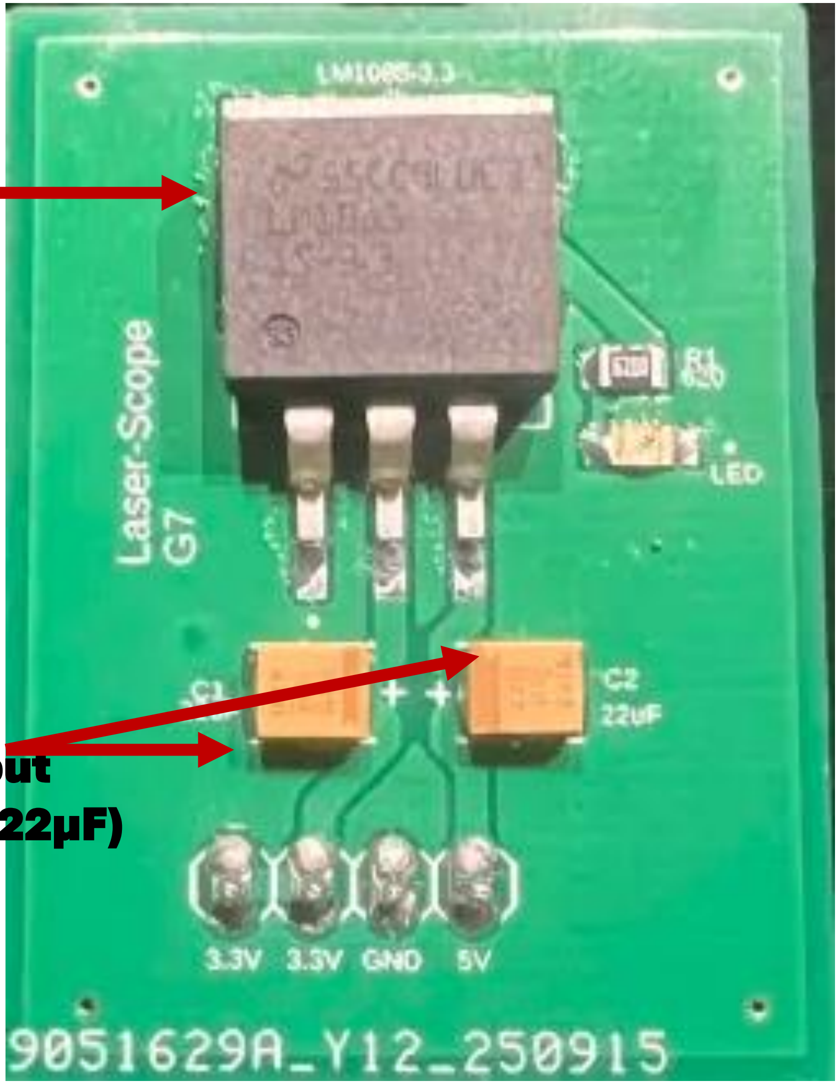


PCB Design – 3.3V Regulator



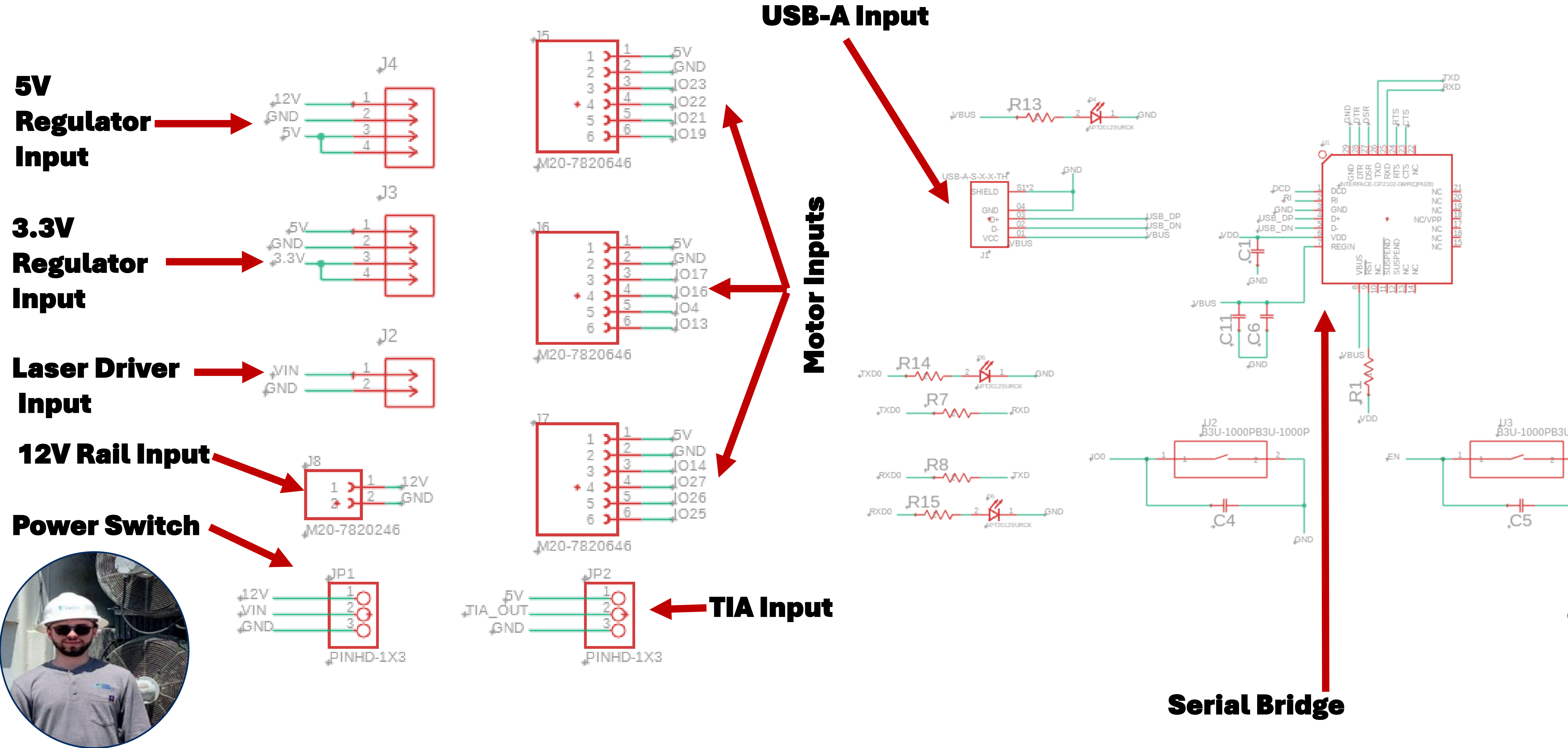
PCB Design – 3.3V Regulator

LM1085-3.3

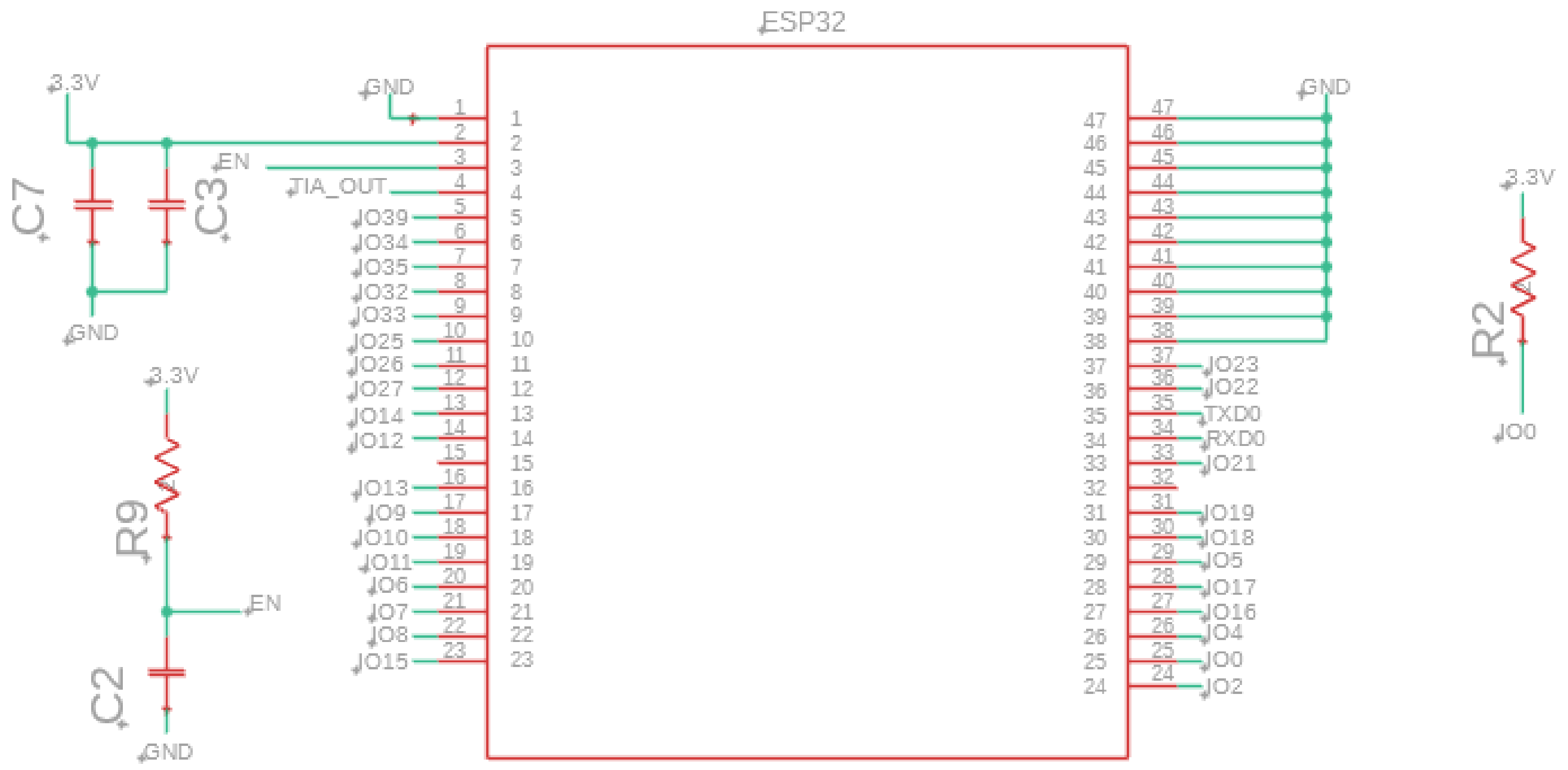


Input & Output
Capacitors (22µF)

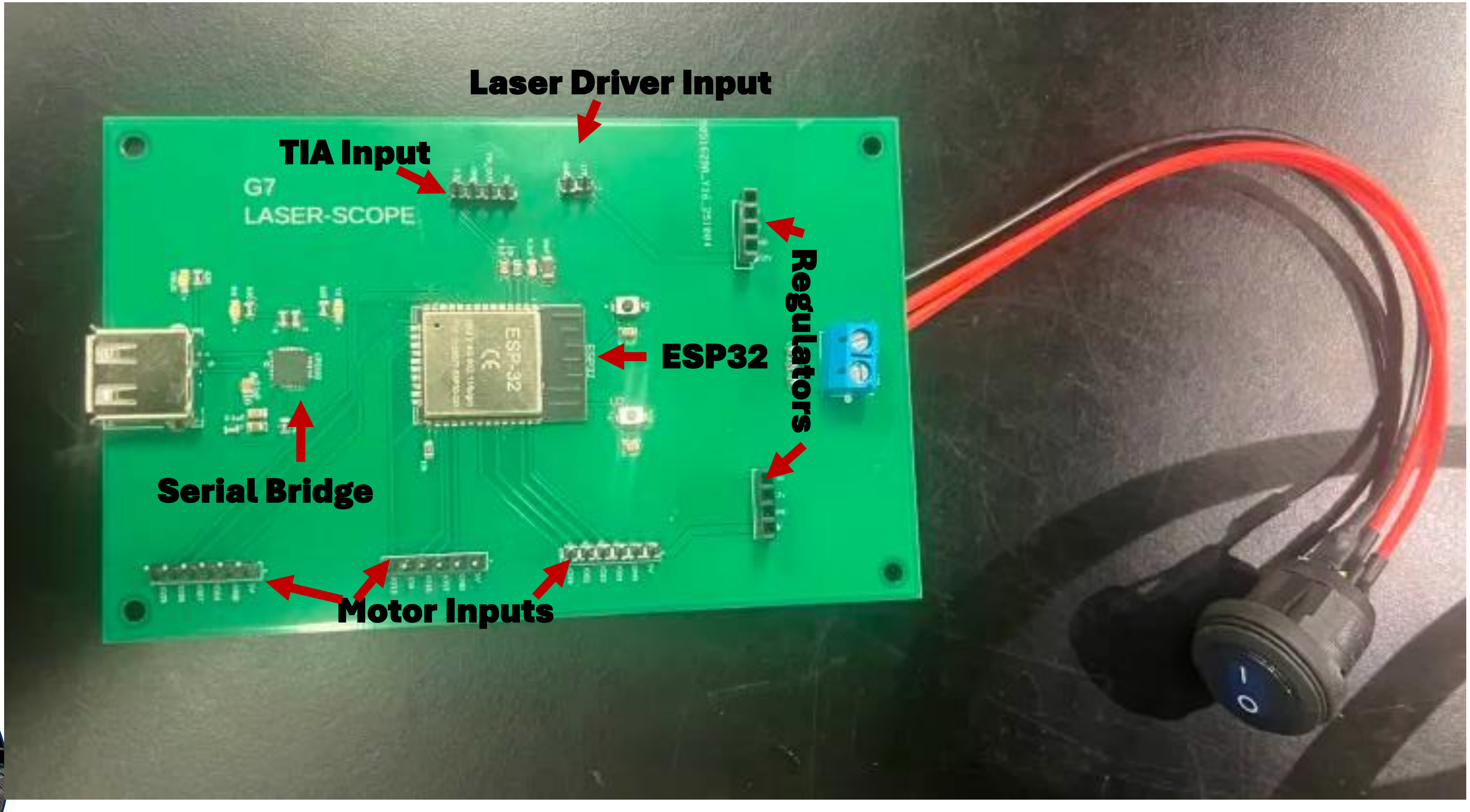
PCB Design – Main Board



PCB Design – Main Board



PCB Design – Main Board



Software: Data Gathering – ADC

The ESP32 is responsible for gathering ADC values from the transimpedance amplifier (TIA). The GUI utilizes the serial communication to send a command to the MCU that the ESP32 interprets.

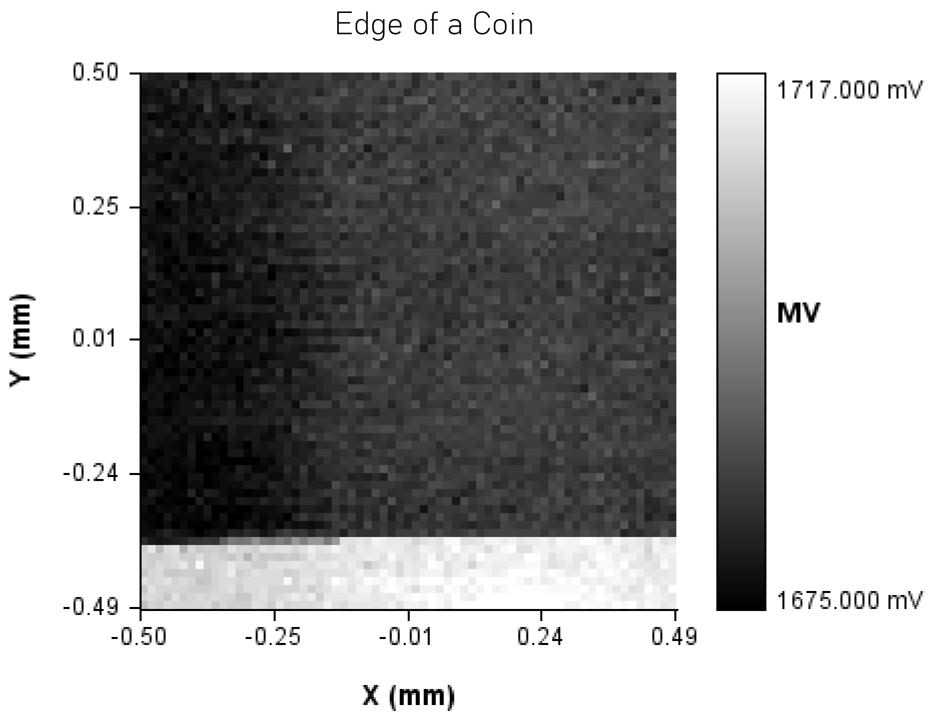
The ESP32 responds with a serial print statement that the GUI uses for ADC readings in the configuration and for when we scan to create a CSV file.

x_mm	y_mm	z_mm	raw	mv	conv_us	v	idx	total	timestamp_ms
-0.5	0.5	0	2193	1921	45	1921	1	2601	5687
-0.48	0.5	0	2195	1920	41	1920	2	2601	5899
-0.46	0.5	0	2196	1919	42	1919	3	2601	6104
-0.44	0.5	0	2192	1921	42	1921	4	2601	6317
-0.42	0.5	0	2192	1922	42	1922	5	2601	6521
-0.4	0.5	0	2161	1923	41	1923	6	2601	6735
-0.38	0.5	0	2175	1929	42	1929	7	2601	6940
-0.36	0.5	0	2195	1920	41	1920	8	2601	7153
-0.34	0.5	0	2200	1925	42	1925	9	2601	7357
-0.32	0.5	0	2204	1925	41	1925	10	2601	7571
-0.3	0.5	0	2216	1932	42	1932	11	2601	7776
-0.28	0.5	0	2204	1920	41	1920	12	2601	7989
-0.26	0.5	0	2206	1930	42	1930	13	2601	8194
-0.24	0.5	0	2211	1933	41	1933	14	2601	8407
-0.22	0.5	0	2209	1932	42	1932	15	2601	8611
-0.2	0.5	0	2257	1921	41	1921	16	2601	8826
-0.18	0.5	0	2160	1892	42	1892	17	2601	9030
-0.16	0.5	0	2194	1916	42	1916	18	2601	9244
-0.14	0.5	0	2192	1916	42	1916	19	2601	9447
-0.12	0.5	0	2187	1913	41	1913	20	2601	9661
-0.1	0.5	0	2181	1911	42	1911	21	2601	9867
-0.08	0.5	0	2181	1918	42	1918	22	2601	10080
-0.06	0.5	0	2207	1933	42	1933	23	2601	10284
-0.04	0.5	0	2210	1933	41	1933	24	2601	10495
-0.02	0.5	0	2153	1883	41	1883	25	2601	10699

Software: Data Imaging

After the process of scanning a sample, it will produce a CSV file. This file is saved to where the user chooses.

To get an image we get this new CSV file and put it through our CSV process to generate an image on the right.



This image shows the dimensions of the scan (1x1 mm)

The mV Range of the scan
(Low value / Dark low Height High value / Light High Height).

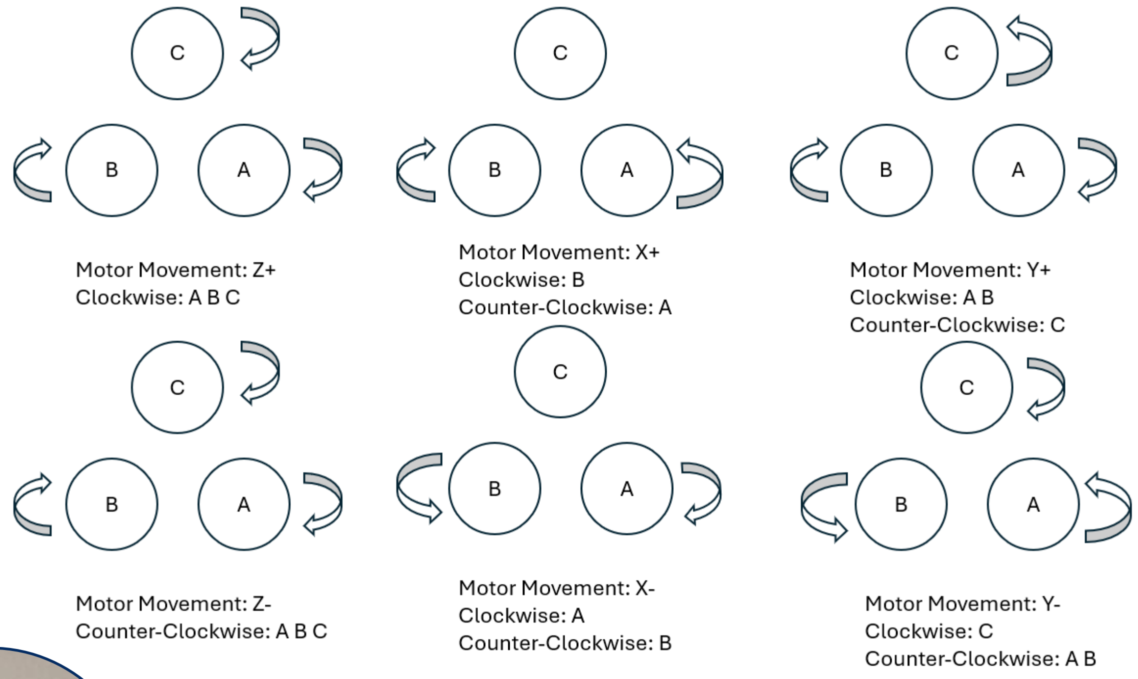
Software: Motor Control (1/2)

The OpenFlexure Delta stage relies on the coordinate effort of three motors to move the stage on 3 different axis.

The motors turn gears that manipulate the driving arm of the stage. The following matrix shows the combination of motor movements to translate the stage in the X,Y,Z direction

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} -\cos(30) & \cos(30) & 0 \\ \cos 60 & \cos(60) & -1 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

Software: Motor Control (2/2)

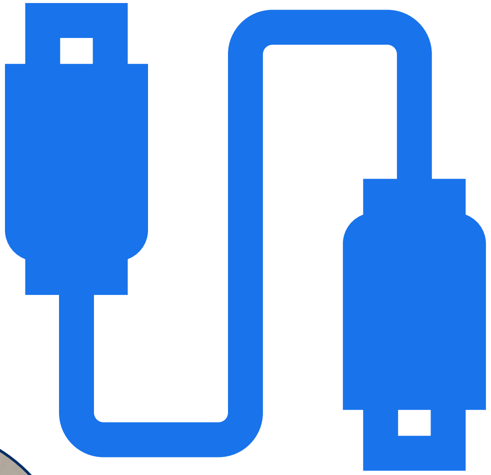


Upon booting up the ESP32 the stage is set at a relative origin.

The organization of the motors is significant to stage movement and creating good images.

If any of the motors were to rotate not in accordance with desired direction reduces the quality of the image significantly.

Communication Protocol



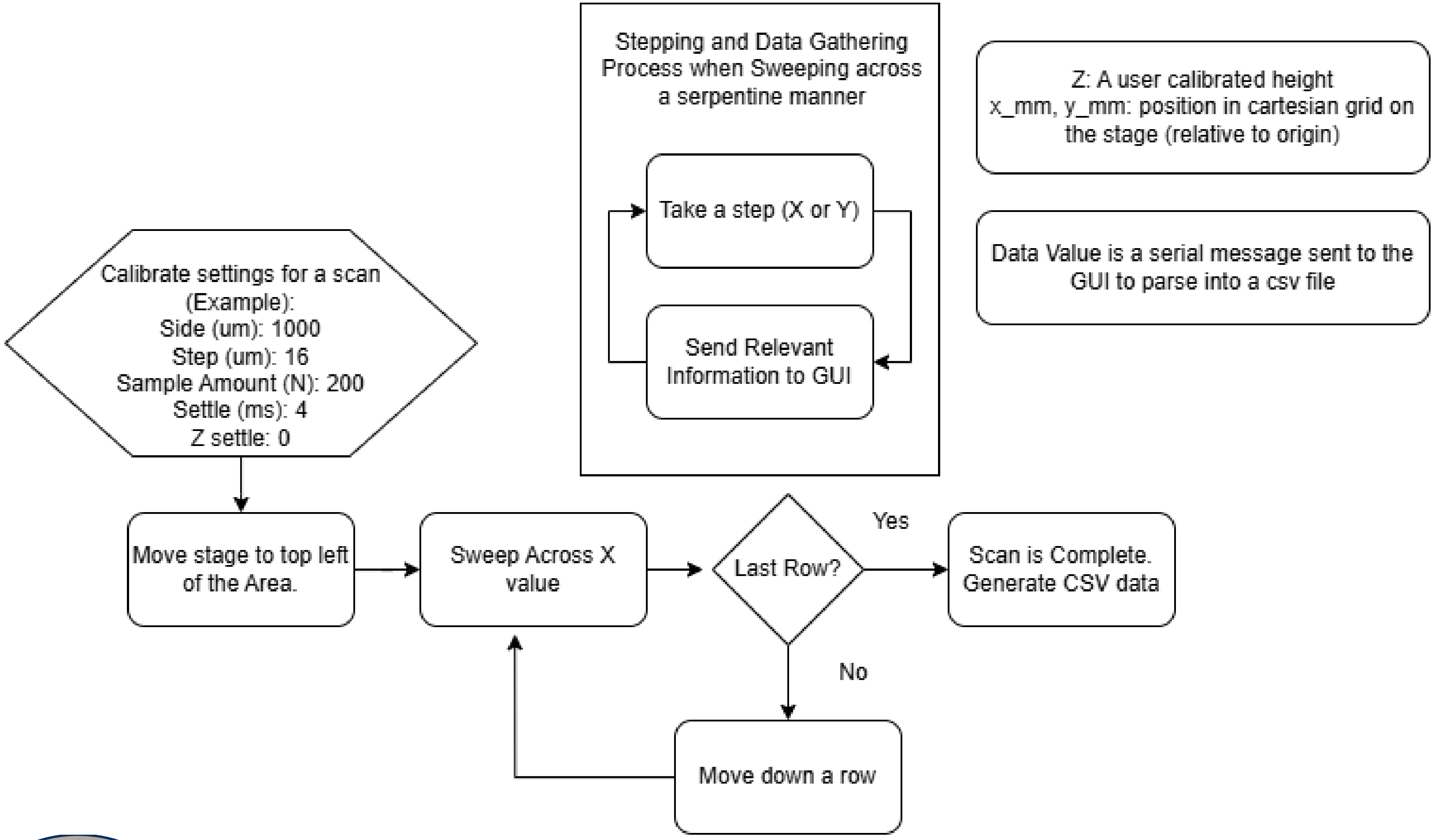
The communication protocol used is USB to Serial.

The SerialManager class is the pipeline for communicating with the ESP32.

Uses:

- Establishing Connection with ESP32
- Sending Commands to ESP32
- Receiving Data and Status pertaining to scan and motor position.

Software Diagram: Object Scanning Process



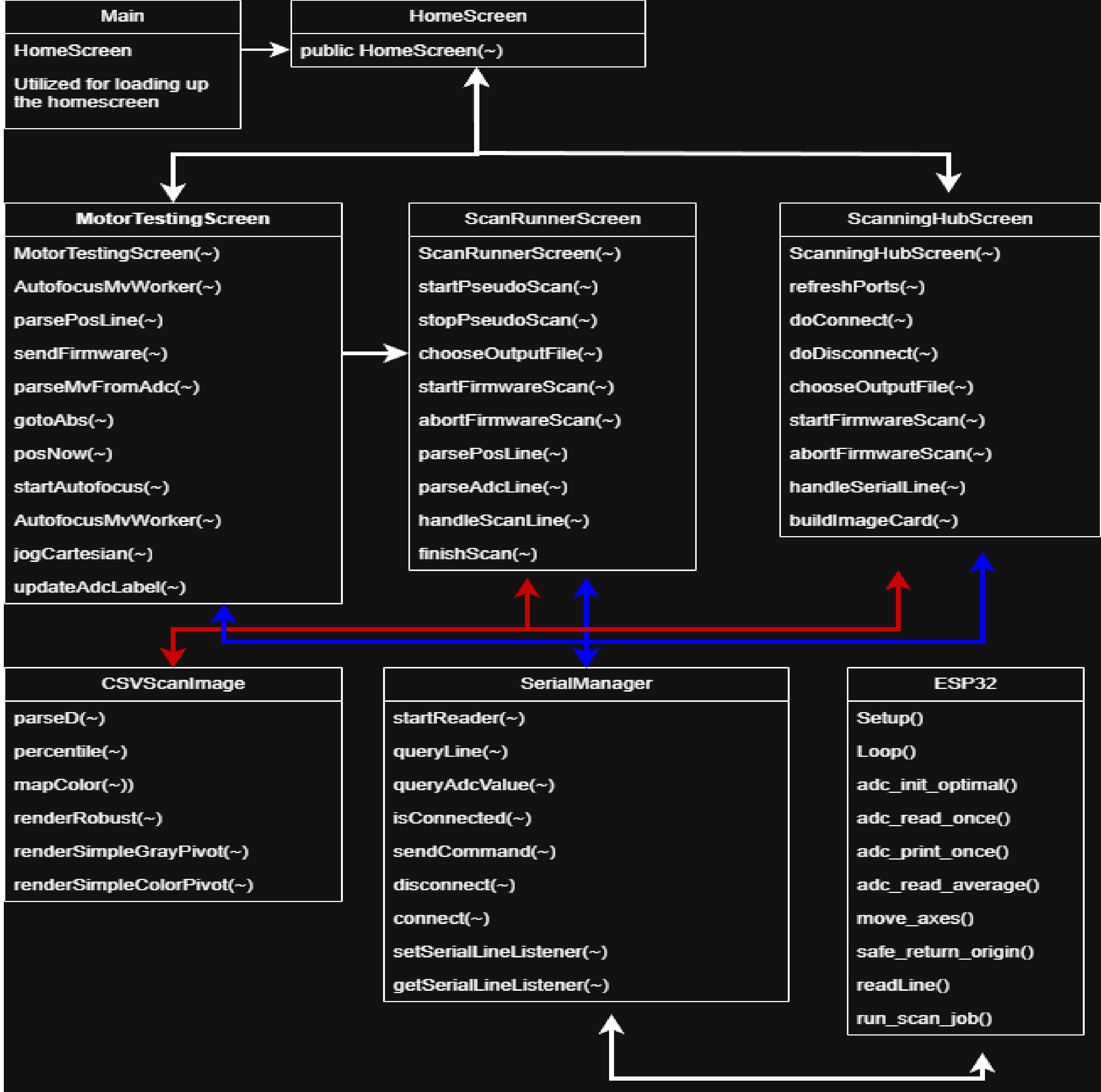
Math for Time Estimation

$$t_{comm} = serial\ comm.\ overhead$$
$$t_{ADC} = Time\ to\ scan\ N\ samples$$
$$t_{move} = \ \mu s\ delay\ in\ movement\ between\ points$$
$$\mathrm{R} = \text{resolution of scan}$$
$$N_{completed} = number\ of\ completed\ points\ in\ scan$$
$$t_0 = ms\ at\ scan\ start$$
$$t_{now} = \text{ms at current moment}$$

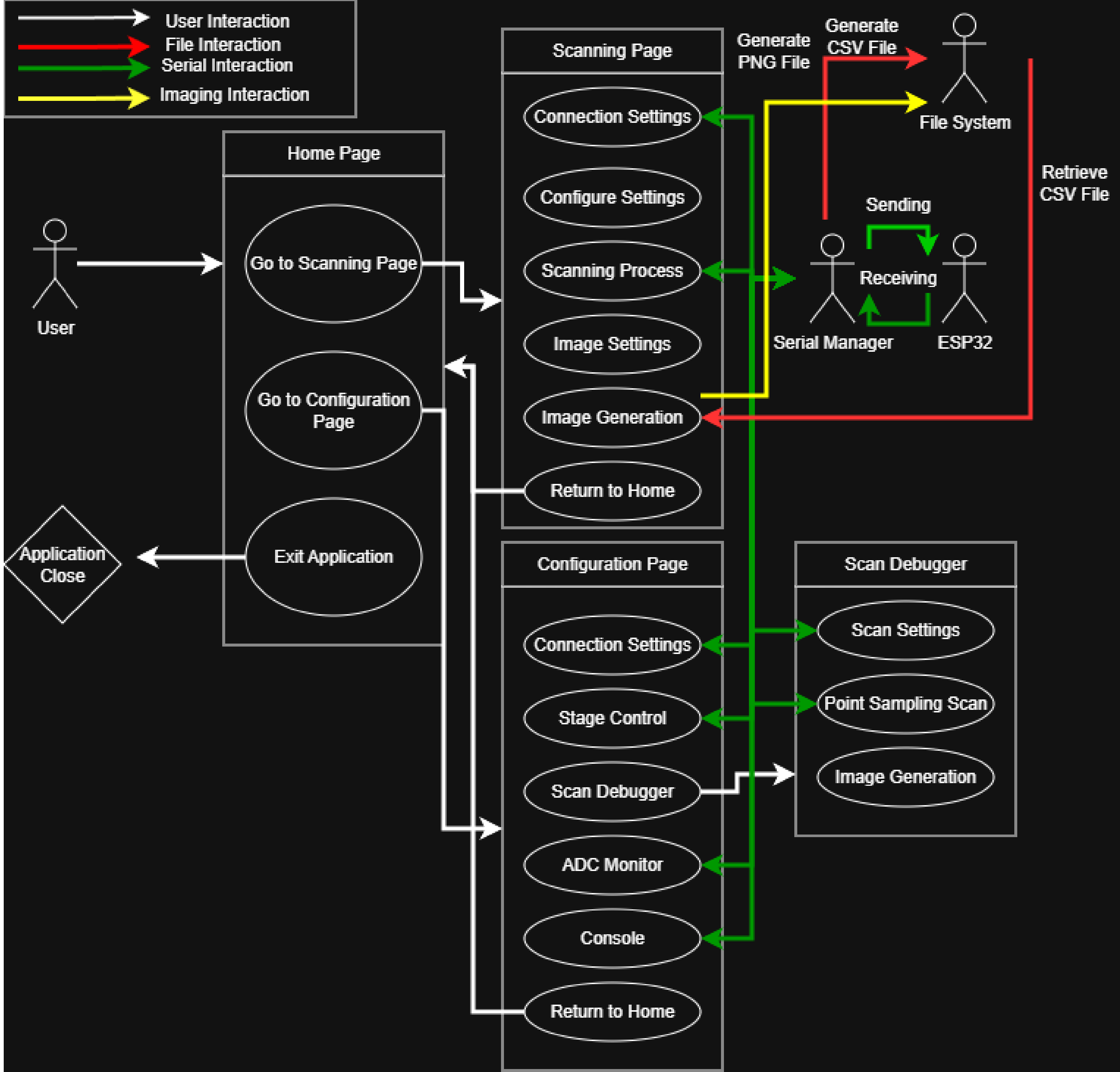
$$t_{point} = t_{comm} + t_{ADC} + t_{move}$$
$$t_{total} = R^2 \times t_{point}$$

$$t_{per-point} = \frac{t_{now} - t_0}{N_{Completed}}$$

Software Diagrams: Class



Software Diagrams: Use Case



Software: Programming Languages

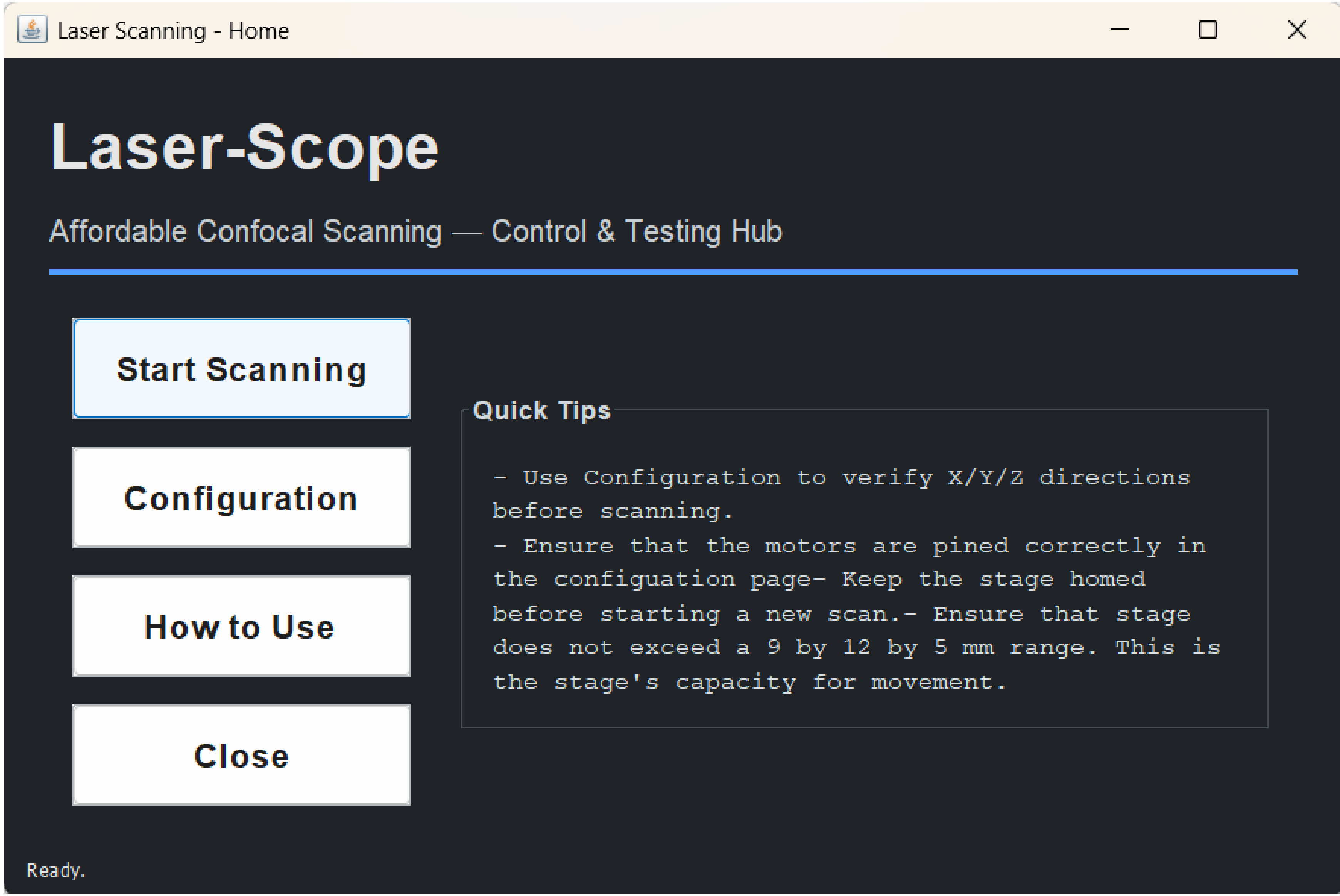
Language	ESP32	Raspberry PI	Arduino Mega
C	Supported	Supported	Supported
C++	Supported	Supported	Supported
Python	Not Supported	Supported	Not Supported
MicroPython	Supported	Not Supported	Not Supported
Circuit Python	Supported	Not Supported	Not Supported
JavaScript	Not Supported	Supported	Not Supported

Software: GUI Packets

Programming Language	Software Package	Key Features	Strengths
Python	Tkinter	Built-in GUI toolkit, basic widgets	Simple, easy to learn, no extra setup
	PyQt / PySide	Qt framework binding, advanced widgets	Modern design, professional interfaces, cross-platform
	Kivy	Cross-platform, touch support, kv language	Mobile-friendly, flexible layouts, Android/iOS support
	DearPyGui	GPU-accelerated, fast plotting, easy setup	Rapid development of dashboards, high rendering speed
C# (.NET)	Windows Forms (WinForms)	Classic drag-and-drop designer	Fast development, easy for beginners
	WPF (Windows Presentation Foundation)	XAML-based, advanced graphics, animations	Modern visuals, data binding, responsive layouts
C++	Qt	Cross-platform, extensive widget set, advanced graphics	High performance, native look, scalable
	wxWidgets	Native-looking GUI, minimal dependencies	Simple cross-platform GUIs, open-source
Java (Selected ✓)	Swing	Classic Java GUI toolkit, basic widgets	Stable, easy to integrate, cross-platform
	JavaFX	Modern UI with CSS styling, animations	Polished visuals, hardware acceleration
	JFreeChart	Charting library for data visualization	Professional-quality charts, easy integration

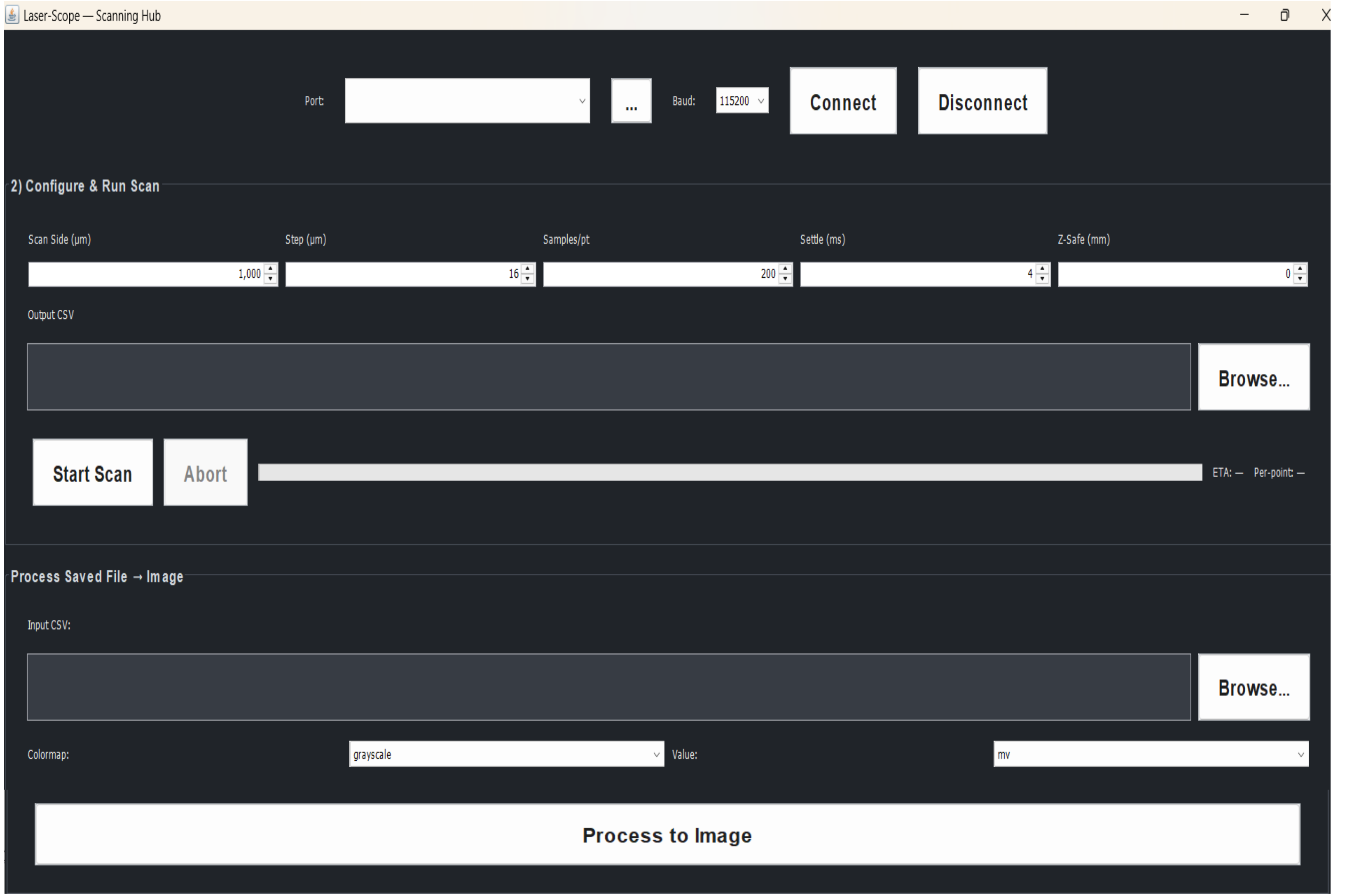
Software: Graphical User Interface

Homepage



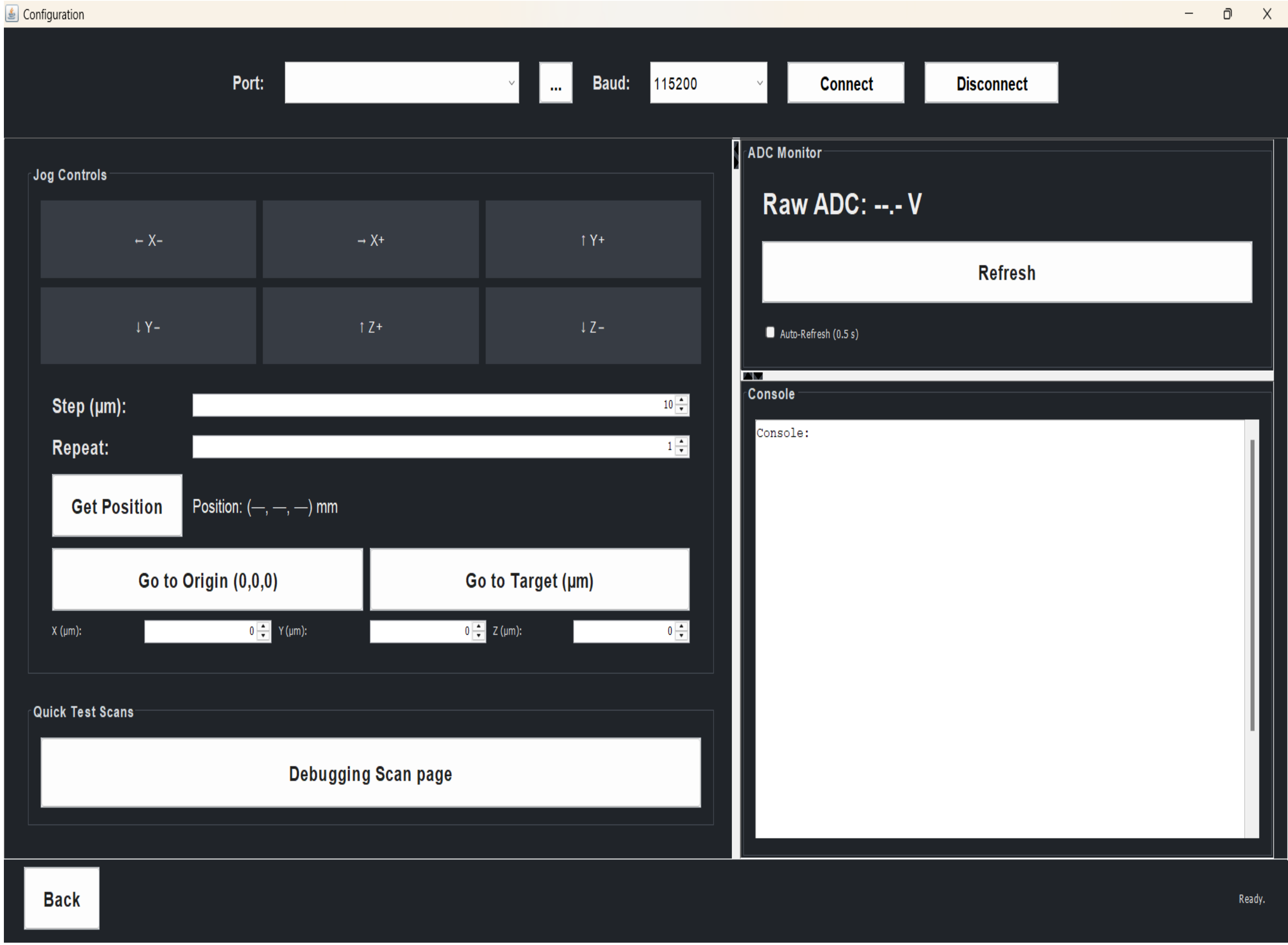
Software: Graphical User Interface

Scanning Page

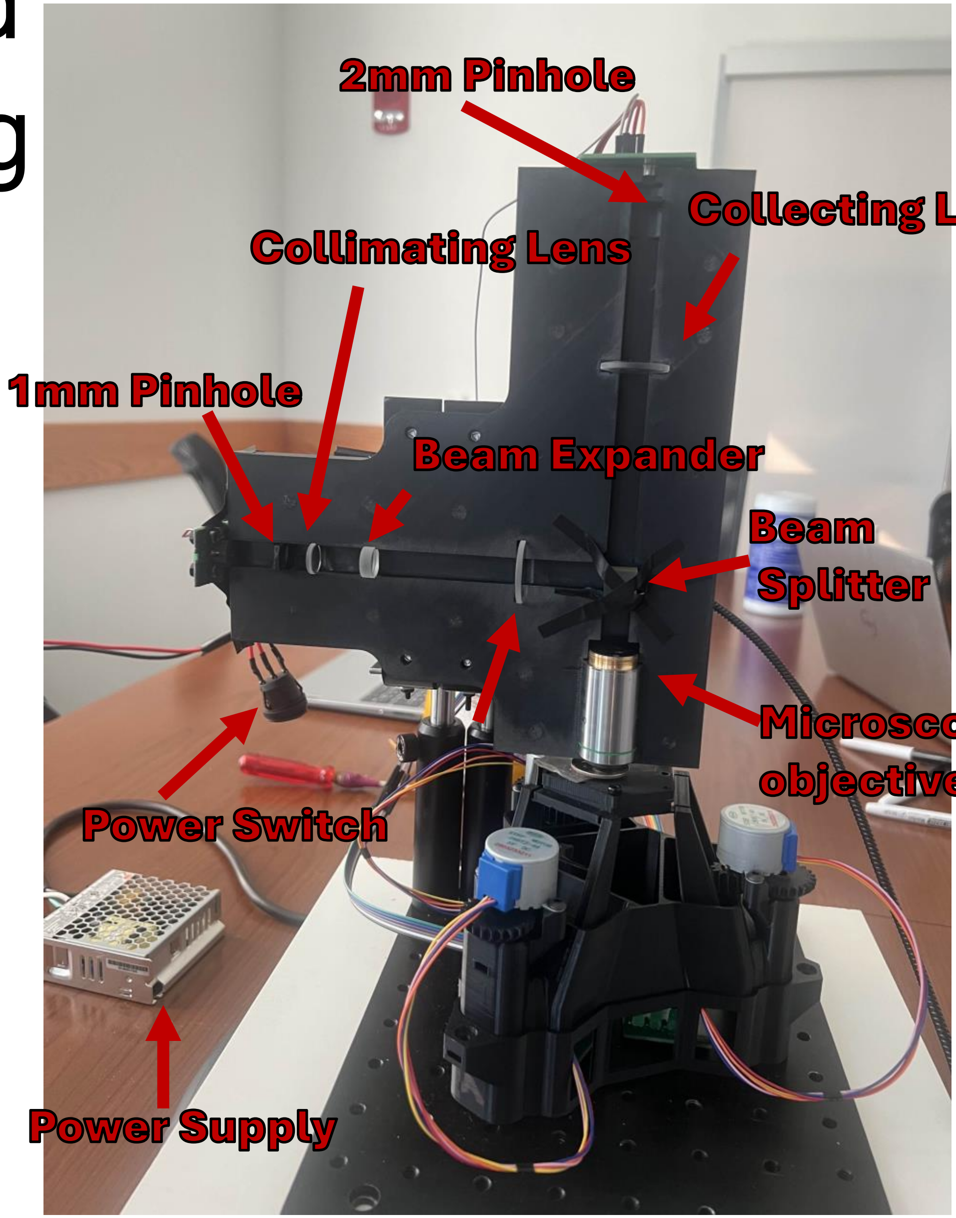


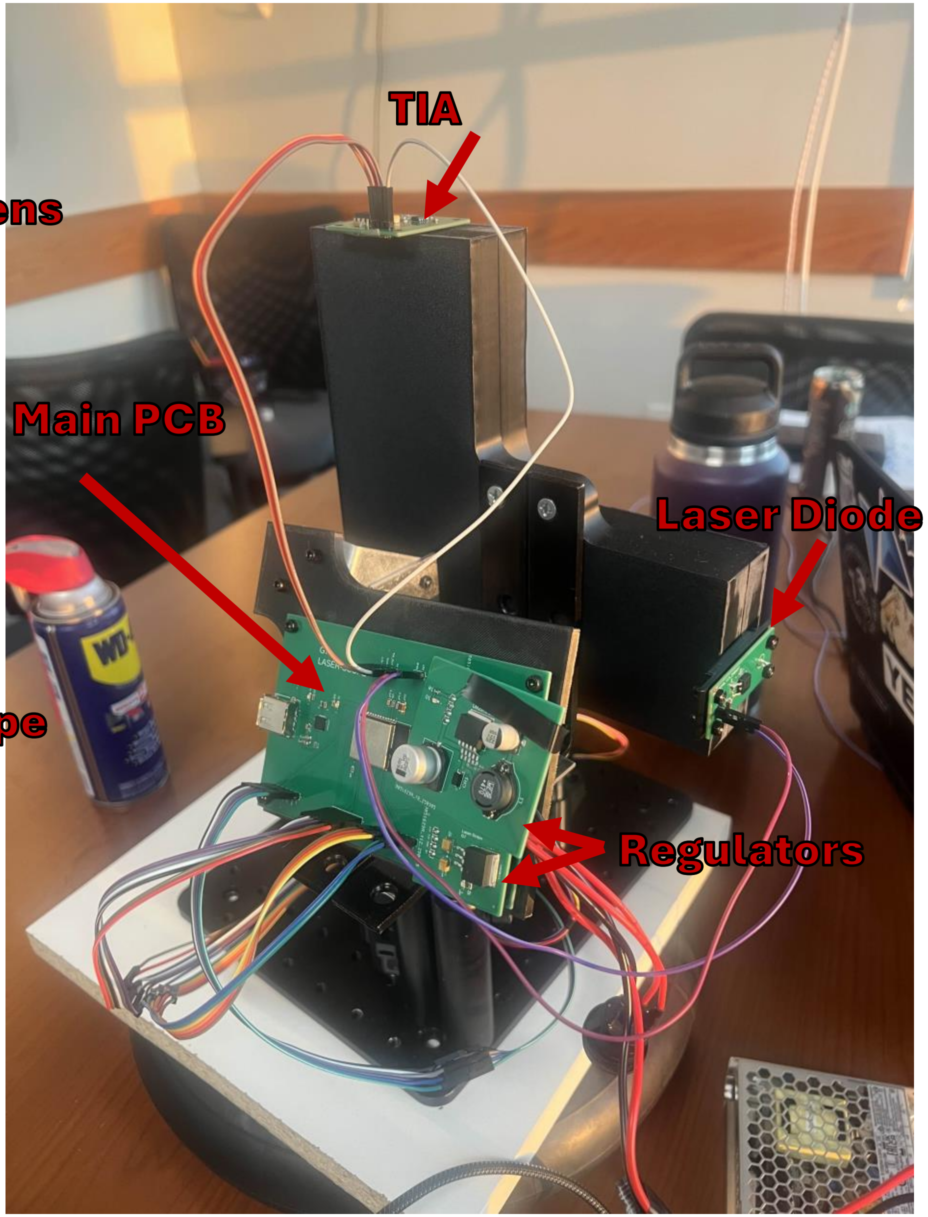
Software: Graphical User Interface

Configuration



Testing and Prototyping Overall System





Testing and Prototyping – Time Scale for 2D Images

$$Step\ Size = \sqrt{\frac{Scan\ size}{Resolution}}$$

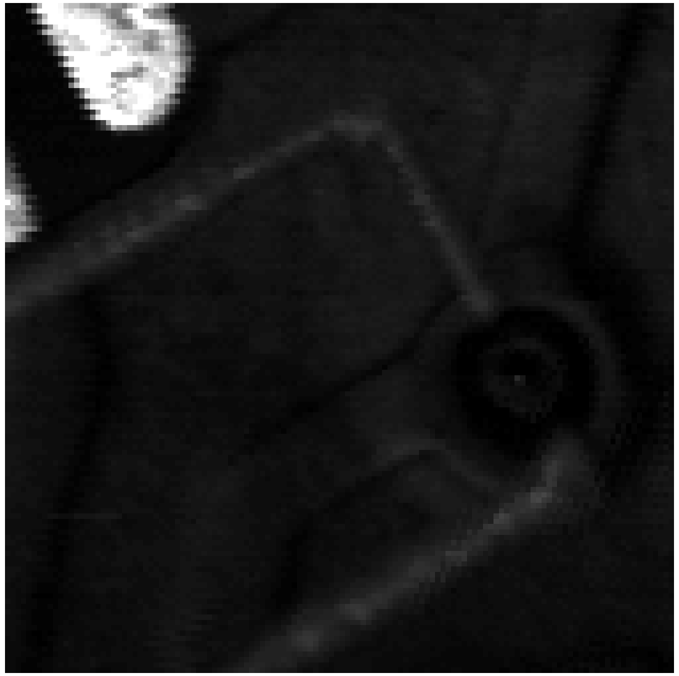
$$i.e., 1x1mm\ (@\ 64x64\ px)$$

$$Step\ Size = \sqrt{\frac{1mm^2}{64px^2}} = 15.6\mu m$$

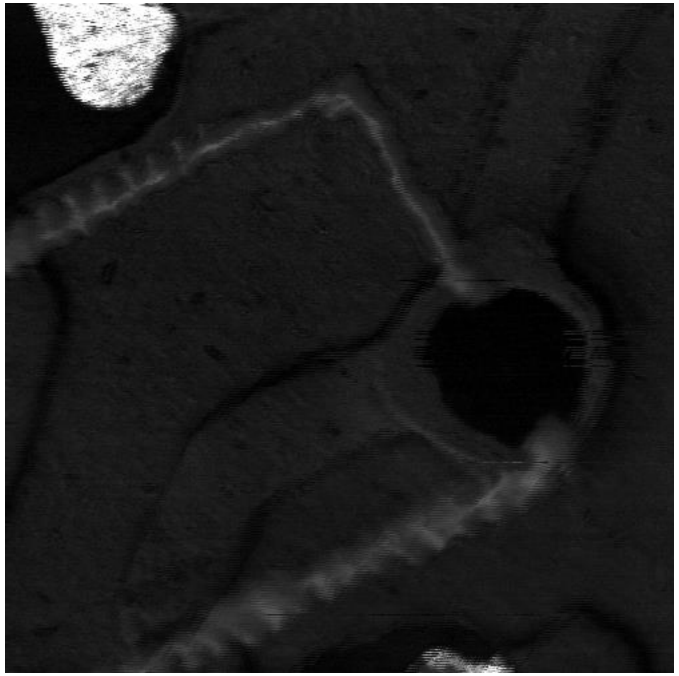
Scan Size Area	Step Size (resolution)	Samples/px	~Total Scan Time (Hr : Min : Sec)
1x1 mm	16µm (63x63 px)	100/pt	20:00
1x1 mm	16µm (63x63 px)	500/pt	23:00
1x1mm	8µm (126x126 px)	500/pt	41:00
2x2mm	32µm (63x63 px)	200/pt	46:00
2x2mm	16µm (126x126 px)	200/pt	1:30:00
5x5mm	80µm (63x63 px)	200/pt	1:45:00
5x5mm	40µm (126x126 px)	200/pt	3:30:00
5x5mm	20µm (251x251 px)	200/pt	7:00:00
5x5mm	10µm (501x501 px)	200/pt	10:00:00

Testing and Prototyping – 2D Images (PCB)

2 x 2mm scan area
63 x 63 pixels

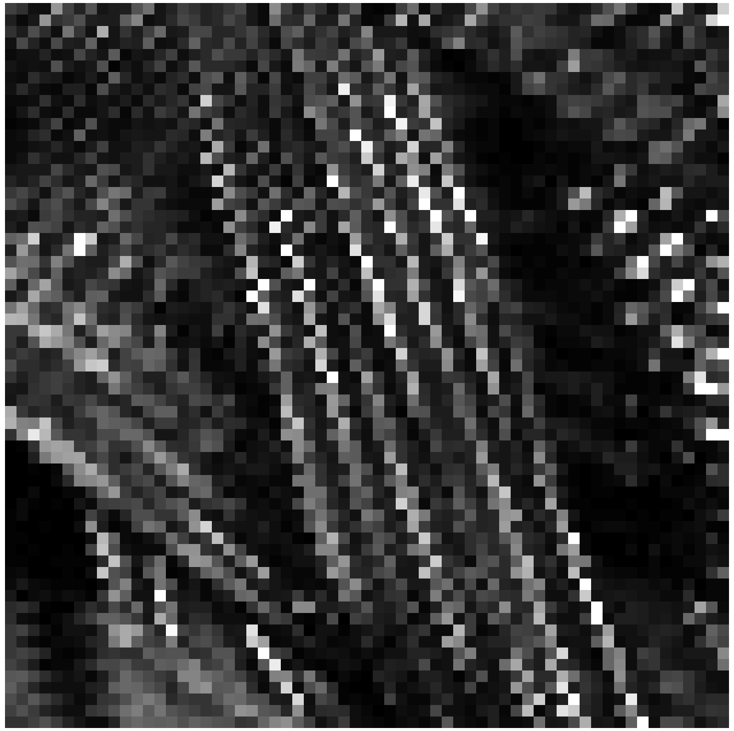


2 x 2mm scan area
126 x 126 pixels



2 x 2mm scan area
501 x 501 pixels

Testing and Prototyping – 2D Images (Solder Wick)



1x1 mm scan area
63 x 63 pixels

1x1 mm scan area
126 x 126 pixels

Testing and Prototyping – 2D Images (Quarter lettering)

"In God
We
Trust"

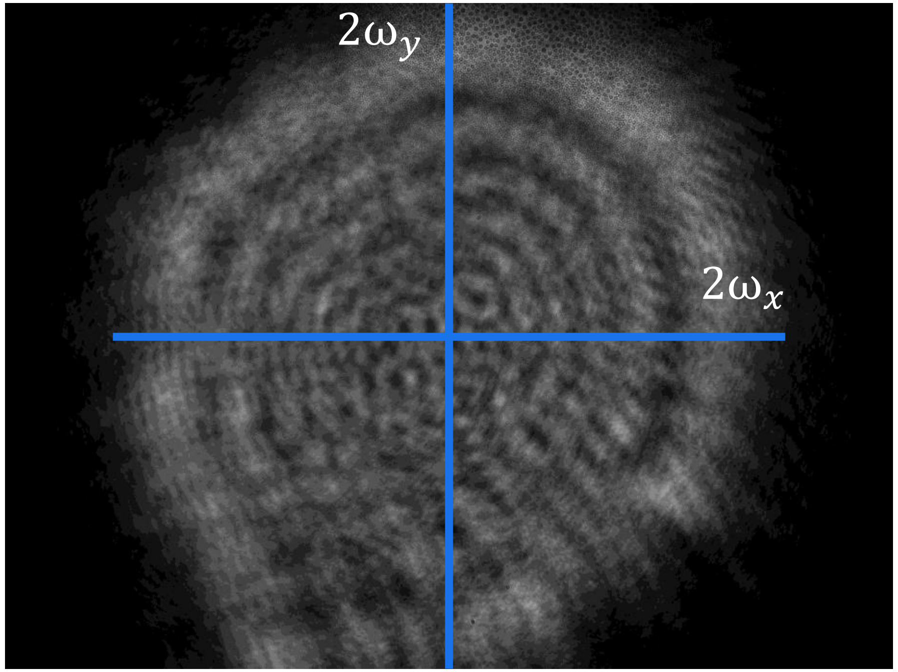
1x1 mm scan area
63 x 63 pixels

2x2 mm scan area
63 x 63 pixels

2x2 mm scan area
63 x 63 pixels

Testing and Prototyping – Airy Disk Spot Size at Microscope Focus (1/2)

	A	B	C	D
1		w_x (um)	w_y (um)	w_avg (um)
2	pic1	4031	3023	3527
3	pic2	4371	3027	3699
4	pic3	3324	2539	2931.5
5	pic4	3337	4037	3687
6	pic5	3686	2602	3144
7	pic6	5696	3089	4392.5
8	pic7	5180	2852	4016
9	pic8	5098	3122	4110
10	pic9	4840	2583	3711.5
11	pic10	5496	3114	4305
12			total avg waist	3752.35



*Example picture of the beam before the objective lens

By calculating the average beam waist radius before the objective lens, we can use that value to calculate the spot size at the focus

Testing and Prototyping – Signal Noise Ratio

$$SNR = 20\log_{10}\left(\frac{\mu_{Focus}}{\sigma_{Noise}}\right)$$

$$SNR_{Rlow} = 20\log_{10}\left(\frac{1684.755}{3.126391}\right) = 54.63dB$$

$$SNR_{Rhigh} = 20\log_{10}\left(\frac{1786.869}{3.362376}\right) = 54.51dB$$

Desc. Of Variable	Value
Average of low reflectivity sample	1684.755
Standard Deviation of noise of low reflectivity sample	3.126391
Average of high reflectivity sample	1786.869
Standard Deviation of noise of high reflectivity sample	3.362376

Testing and Prototyping – Airy Disk Spot Size at Microscope Focus (2/2)

$$f = \frac{L}{M} = \frac{180mm}{20} = 9mm$$

$$NA_{Max} = \frac{EP}{2f} = \frac{8.3mm}{2(9mm)} = 0.461$$

$$NA_{eff} = NA_{Max}\left(\frac{2\omega_{avg}}{EP}\right) = 0.461(\frac{2(3.752mm)}{8.3mm}) = 0.417$$

$$\omega_{spot} = \frac{1.22\times\lambda}{NA_{eff}} = \frac{1.22(405nm)}{0.417} = 1.185\mu m$$

Desc. Of Variable	Variable	Value
NA of 20x Obj	NA	0.4
Tube Length	L	180mm
Entrance Pupil Diam. Of 20x obj.	EP	8.3mm
Wavelength of Laser	λ	405nm
Magnification of Obj.	M	20x
Entrance Beam Diam.	$2\omega_{avg}$	7.504mm

Problems & Proposed Solutions

Problem: At the low end of the working range the TIA dips below the ESP32's ADC working range ~80mV, as such the ADC readout begins malfunctioning

Proposed Solution: Bias the TIA at the + input, effectively shifting the range by 1.65V ensuring a proper working range for the ESP32's internal ADC

Problems & Proposed Solutions

Problem: 3D printed gears sticking.

Proposed Solution: Regular maintenance is required after every 5 scans to avoid gears getting stuck during scans

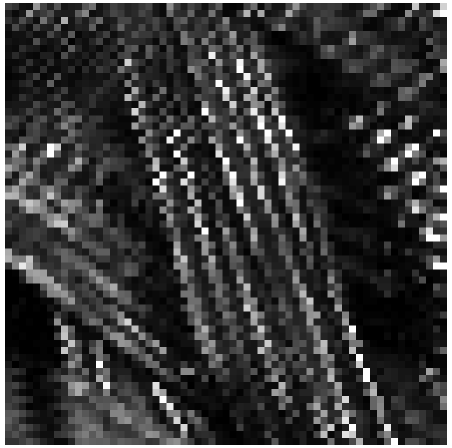
Image with gears sticking

Image with gears not sticking

Problems & Proposed Solutions

Problem: Truncated step size during scan

Proposed Solution: Modify the program to not truncate the values of the step size. This px becomes exponential for larger scan



1x1mm
63x63 px ->
Total loss of 127 px total

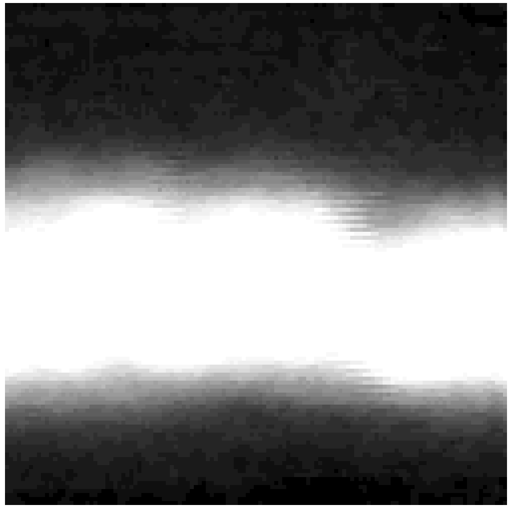
1x1mm
125x125 px ->
Total loss of 759 px

Problems & Proposed Solutions

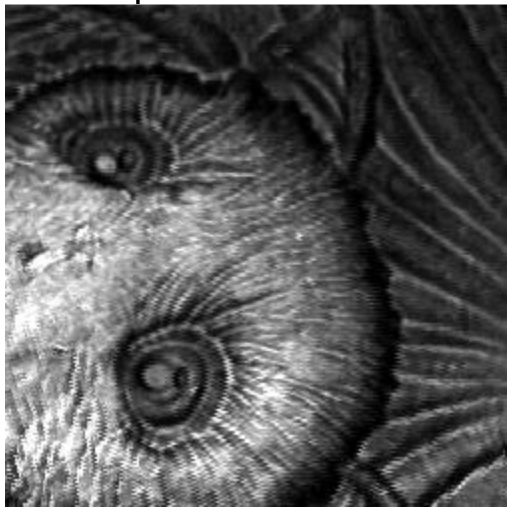
Problem: Mismatch of the TIA's settle time vs. the settle time utilized by the code created a 7% loss of contrast

Proposed Solution: decrease capacitor size from 68nF -> 680pF decreasing settle time from 132ms to 3.2ms

68nF



680pF



Light and dark areas of a quarter meant to show the difference in contrast based on adjustment of the settle time.

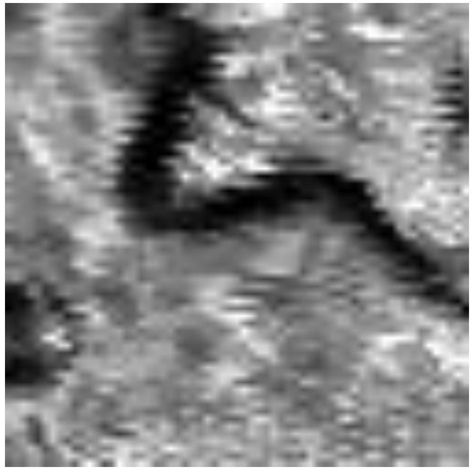
Image on the left is 126x126 px, Image on the right has a resolution of 251x251 px. However, image size on left is 1x1 mm, the left Is 5x5 mm

Problems & Proposed Solutions

Problem: Mismatch between “Scan Side” in GUI vs. actual image size scanned

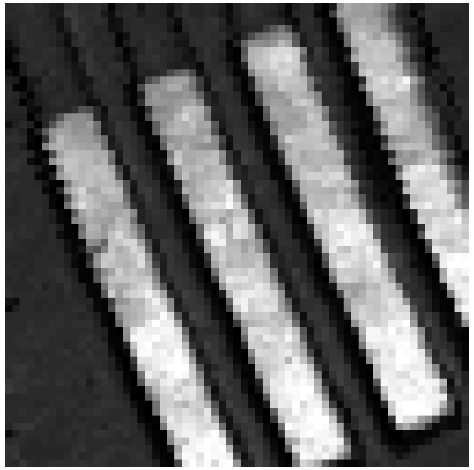
Proposed Solution: Creation of a proper variable to calibrate motor steps

Before Fix



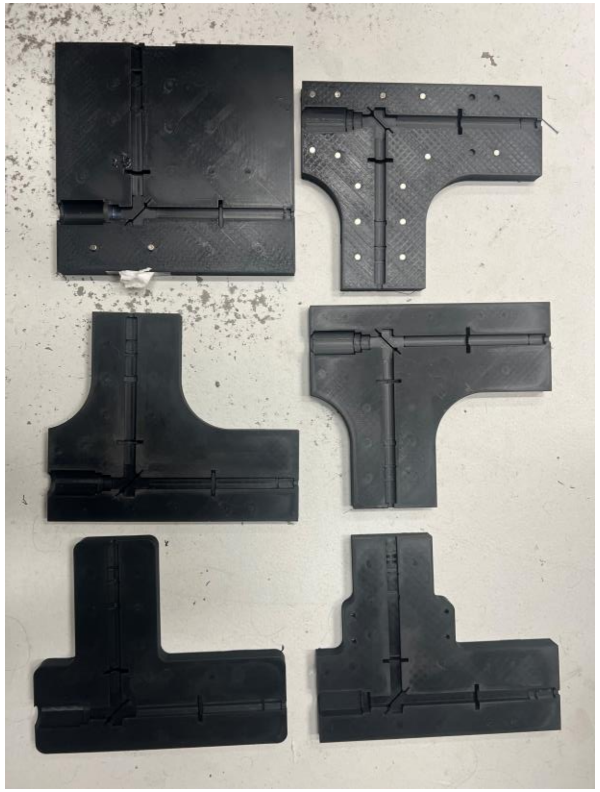
2x2 mm image in GUI, Real size = 1x1 mm

After Fix



2x2 mm image in GUI, Real size = 2x2 mm

Problems & Proposed Solutions



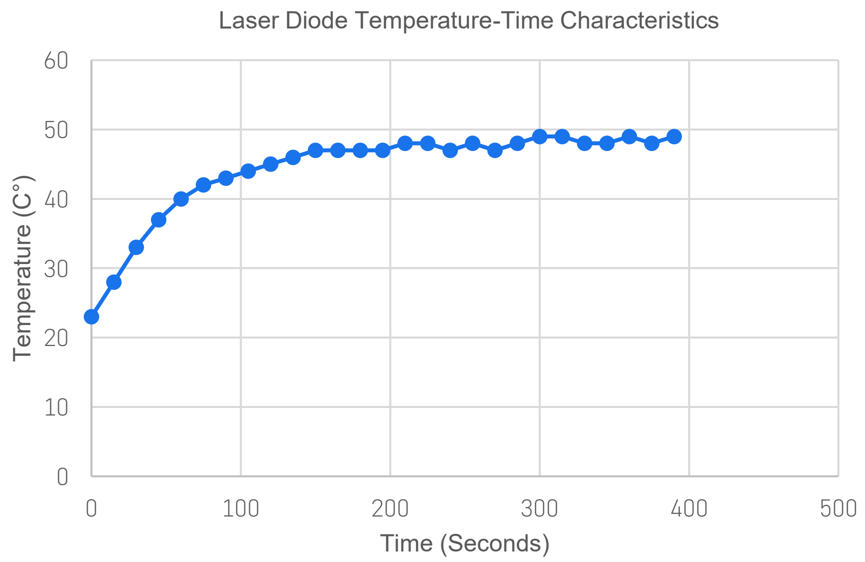
Some of the housing iterations shown above

Problem: Optical alignment is not perfect due to 3D printed parts

Proposed Solution: Through iterations of the microscope housing and utilizing different techniques while printing we can account for most of the misalignment in the optical system

Problems & Proposed Solutions

Problem: Due to higher fluctuations in temperature of the laser diode than expected, the wavelength shifts



Proposed Solution: Let the laser diode have a warmup cycle to get to a stable temperature. This stable temperature is where the wavelength of the diode matches our design wavelength of our system. If the system is not warmed up before scanning all the data will be skewed for the first few minutes as it warms up.

Work Distribution

Photonics Sciences Engineering	Responsibilities
Collin Barber	• Optical component selection and implementation following reflection back through objective • Design for housing of post-objective optics • Photodiode circuit
Photonics Sciences Engineering	**Responsibilities**
Luc Therrien	• Optical Component selection and implementation up until reflection back through the objective • Microscope head • OpenFlexure Delta Stage • Laser power circuit
Computer Engineering	**Responsibilities**
Omar Castro	• MCU Selection and Implementation • Software Design and Implementation • Motor Control • Data Collection • GUI
Electrical Engineering	**Responsibilities**
Karol Josef Woodhouse	• PCB Design • Power Supply • TIA/Filter Design and Signal Cleanup • Stage Motor Implementation

Bill of Material (1/2)

Components	Quantity	Cost
405 nm Laser Diode	1	$50
Photodiode	1	$60
Bi-Concave Lens	1	$40
Plano-Convex Lens	2	$120
Beamsplitter	1	$50
20x microscope objective	1	$60
Bi-Convex Collecting Lens	1	$60
PLA Filament	1	$40
PCBs	1 (Includes all sister boards)	$200
Amplifiers	1	$4.11
Regulator circuits	2	$5
AC/DC converter	1	$12.99
MCU	1	$10
Stepper Motors	3	$8-$15

Bill of Material (2/2)

Components	Quantity	Cost
8”x12” Optical Breadboard	1	$50
Optical Posts and holder	2	$20
1.5” x 1.5” MDF	1	$5
Inner tube	1	$8
Brackets	4	$5
(M3 and ¼”)Screws	1	$5
USB-A to USB-A Cable	1	$6
6 mm Diam. Magnets	1 (includes 200 magnets)	$6
	Total:	$894.11

Progress and Plan For Completion